

MISSISSIPPIAN MARSHALL FORMATION OF MICHIGAN

BY

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in the University of Michigan.

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MISSISSIPPIAN MARSHALL FORMATION OF MICHIGAN¹

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ABSTRACT

The stratigraphy of the Marshall formation should not be studied as an independent unit. The underlying Coldwater shale can be divided into an eastern sandy facies and a western dolomitic facies. The sandy facies is inseparable from the Marshall formation at most places. Redbeds occur in both the Marshall formation and the upper Coldwater sediments in eastern Michigan. They are unreliable as stratigraphic markers except in local areas.

Neither color nor grain size provides a suitable basis for a division of the Marshall into two members throughout the Michigan basin. The coarse-grained Napoleon sandstone (upper Marshall) is a mappable unit in parts of eastern Michigan but loses its identity westward.

The top of the Marshall grades into the overlying Michigan formation. The Michigan "Stray" sandstones are the result of an interfingering of the Marshall and Michigan deposits and should not be considered to be entirely of Michigan age. In addition to the recognized eastern source of sediments for the Marshall formation, a western source is apparent.

INTRODUCTION

Objectives.—This report presents the results of a lithologic study of the Marshall formation of Michigan. Primary problems associated with the study were (1) the stratigraphic relationship of the Marshall formation to the underlying Coldwater shale, (2) the distribution of Mississippian redbeds and their value as stratigraphic markers, (3) the value of a division of the Marshall formation into two distinct members, and (4) the stratigraphic relationship of the Marshall formation to the overlying Michigan formation with particular regard to the Michigan "Stray" sandstone.

Stratigraphic position and areal distribution.—The stratigraphic relationship of the Marshall formation of lower Mississippian age to other formations in Michigan is shown in Figure 1. Marshall beds everywhere rest on the Coldwater formation and at most places are overlain by the clastic and chemically precipitated deposits of the Michigan formation. On the flanks of the Howell anticline in Livingston County and on at least two of the anticlines in the southeastern part of Bay County Marshall strata are overlain unconformably by Pennsylvanian rocks. The Marshall has been completely removed from the tops of these folds and Pennsylvanian rocks or glacial drift rest directly on the Coldwater shale.

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The field work was accomplished with finances and transportation furnished by the Michigan Department of Conservation, Geological Survey Division. Miss Helen M. Martin and other members of the Michigan Geological Survey staff have been most cooperative.



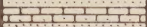
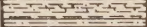
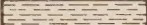
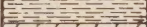
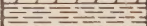
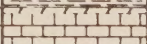
SYSTEM	SERIES	GROUP	FORMATION OR MEMBER	LITHOLOGY	DESCRIPTION	THICKNESS
PLEISTOCENE			WISCONSIN AND ILLINOIAN?		GRAVEL, SAND, CLAY, AND TILL	0-860
CARBONIFEROUS	PENNSYLVANIAN		GRAND RIVER		SANDSTONE, SANDY SHALE, SHALE AND THIN COAL	80-95
		POTTSVILLE	SAGINAW		SANDSTONE, SANDY SHALE, SHALE, THIN COAL BEDS AND LIMESTONE	400-535
					LIMESTONE, BROWNISH-GRAY, AND SANDSTONE	40-100
	MISSISSIPPIAN	WERAMEC-OSAGE	BAYPORT		SHALE-GRAY, SANDSTONE-GRAY, GYPSUM, LIMESTONE AND DOLOMITE	0-500
			MICHIGAN		SANDSTONE, RED AND WHITE, SOME SHALE AND SILTSTONE	160-320
		KINDERHOOK	MARSHALL		SHALE-GRAY, SOME RED SHALE, SOME SANDSTONE AND SILTSTONE	500-1000
			COLDWATER		SHALE, BLACK	10-30
			SUNBURY		SANDSTONE, WHITE AND GRAY, AND SHALY	0-210
			BEREA		SANDSTONE	10-300
			MEDFORD		SHALE, GRAY	100-450
			ANTRIM		SHALE, BLACK, SOME GRAY SHALE	100-800
	MIDDLE	TRAVERSE	SQUAW BAY THUNDER BAY POTTER FARM NORWAY POINT FOUR MILE DAM ALPENA NEWTON CREEK GENSHAW FERRON POINT ROCKPORT QUARRY BELL		SHALE, GRAY, LIMESTONE AND CHERTY LIMESTONE, BUFF TO BROWNISH GRAY, SOME DOLOMITE. BEDS VERY FOSSILIFEROUS	0-125
			ROGERS CITY		LIMESTONE AND DOLOMITE, BROWN TO DARK BROWN	0-400
			DUNDEE		DOLOMITE, BUFF TO GRAY, SALT, GYPSUM AND SOME SANDSTONE AT BASE	0-300
			DETROIT RIVER		SANDSTONE, WHITE, FRIABLE, DOLOMITIC, AND SHALE, GREEN	0-1000
			BOIS BLANC		LIMESTONE AND DOLOMITE, BUFF, CHERTY	
DEVONIAN	LOWER					

FIG. 1.—Generalized stratigraphic section of Carboniferous and Devonian for Southern Peninsula of Michigan.

The Marshall formation is confined to the gentle structural basin in the Southern Peninsula of Michigan. It directly underlies the glacial drift of the state in a circular outcrop zone characteristic of formations in the Michigan basin (Fig. 2). The width of the drift-covered outcrop area ranges from 3 to 20 miles. Exposures are limited to Jackson, Hillsdale, and Calhoun counties in southern Michigan, Ottawa County in southwestern Michigan, and Huron, Tuscola, and Sanilac counties in the "Thumb" area of eastern Michigan. The structural basin causes the Marshall formation to occur at increasing depths from the outcrop area toward Clare and Midland counties in the center of the state, where it is more than 1,500 feet below the surface.

The circular pattern of the drift-covered Marshall outcrop is interrupted appreciably in only two areas in the state. Erosion of the Marshall formation from the crest of the Howell anticline in Livingston and Shiawassee counties has extended the outcrop northward in a narrow and poorly defined band along the west and north flank of the structure. Marshall and Coldwater beds directly underlie the glacial drift on the anticlines in Ogemaw and Arenac counties. Well data which have become available since the publication of the geologic map of Michigan (Martin, 1936) indicate that the northern drift-covered outcrops of the Marshall and Coldwater formations swing southward and are continuous with the outcrops of the anticlines in Ogemaw and Arenac counties (Fig. 2).

In the eastern part of the state the contact of the Marshall with the Coldwater formation is indefinite, and in many places indeterminate, due to the presence of fine-grained sandstones and redbeds in the Coldwater. This problem is discussed under the description of the Coldwater formation, but is mentioned here to explain the absence of the Marshall-Coldwater contact line in eastern Michigan in Figure 2.

The outcrop pattern of the Marshall formation in Figure 2 is taken from the geologic map of Michigan (Martin, 1936) with changes in areas where additional information has become available since the publication of the map.

Nature of study.—Most of the information obtained in the study is from subsurface data. Drill cuttings from more than 1,000 wells in the state were examined microscopically. In addition to the examination of well samples, frequent use was made of thousands of driller's logs of wells in Michigan from which samples are not available. These logs were used extensively in the compilation of the structure-contour map (Fig. 19) on the base of the Coldwater shale because this is a stratigraphic marker which is easily recognized by drillers.

Cross sections.—As the upper and lower contacts of the Marshall formation are indefinite in many parts of the state, the best method of illustrating the occurrence of the formation is by cross sections. Six sections aid in presenting and discussing the character of the Coldwater-Marshall interval. In order to illustrate lateral lithologic changes more clearly, these sections were drawn with the well columns aligned on a stratigraphic datum rather than on sea-level. A second section showing the same wells based on sea-level datum is included. Lithologic character and details of correlation are omitted on the structure section.

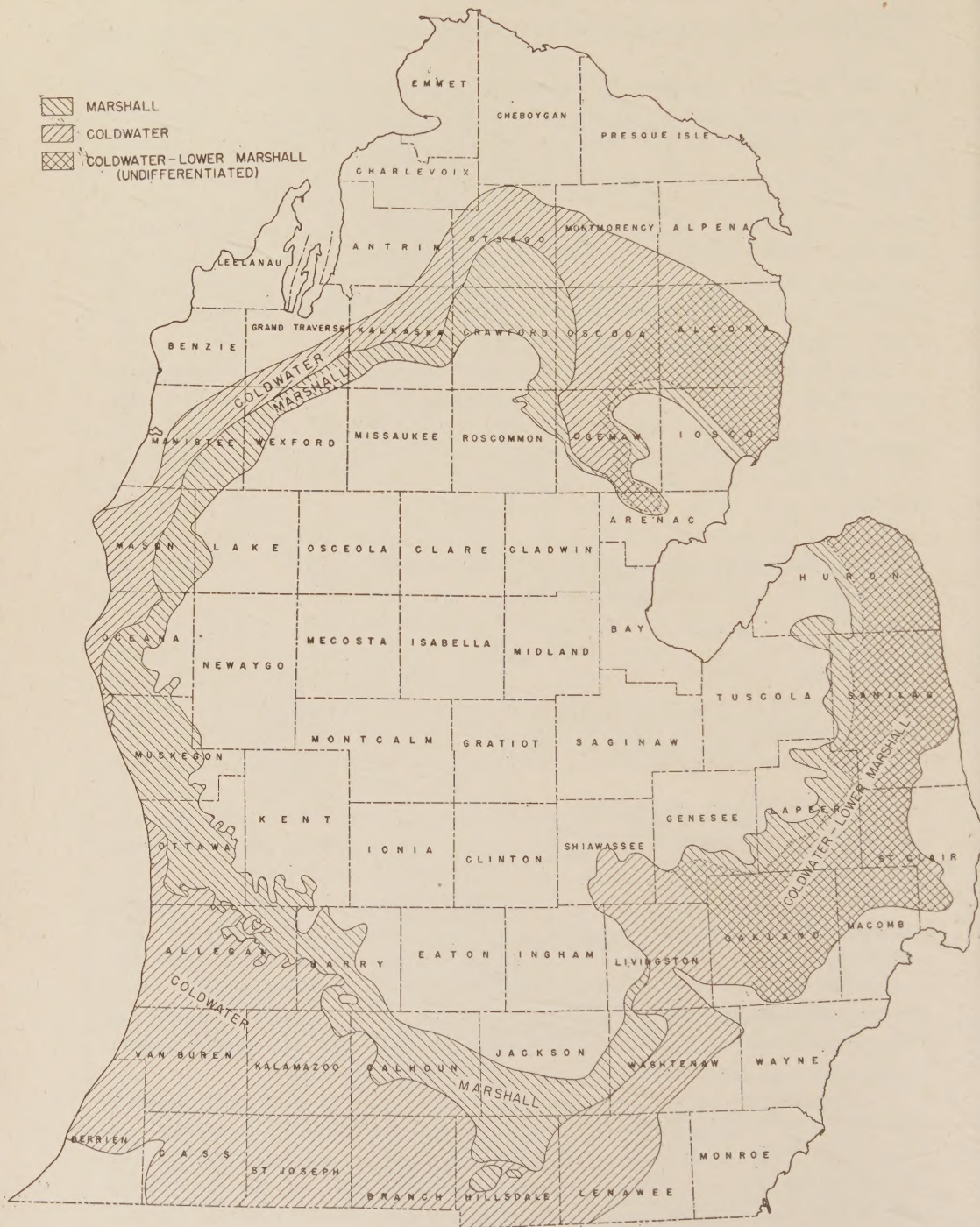


FIGURE 2
BEDROCK MAP OF MARSHALL FORMATION

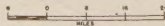


FIG. 2.—Bedrock map of Marshall formation.

All lithologic description shown on the cross sections is determined from well-sample examinations made by the writer with only two exceptions. The lithologic description of well 18 in cross section *BB'* (Fig. 6) is plotted from a written description of the well samples published by the Geological Survey of Michigan. Well 6 in cross section *CC'* (Fig. 7) is plotted from a copy of the driller's log. Lithologic generalizations illustrated in the cross section are avoided where possible, but because of the small vertical scale, it is necessary to generalize the lithologic character of beds having a thickness of less than 10 feet.

Samples of the Coldwater formation are missing in many wells. In a few wells it is necessary to determine the base of the Coldwater from driller's logs supplied by the Geological Survey of Michigan.

The stratigraphic column (Fig. 1) is a reproduction of part of one recently compiled by George V. Cohee of the Ann Arbor, Michigan, office of the United States Geological Survey.

PREVIOUS WORK

Prior to the naming of the Marshall formation by Alexander Winchell in 1861, several geologists described some of the strata which later were assigned to the formation. Douglas Houghton (1838, p. 283) first State geologist of Michigan, referred to the sandstones at Pointe aux Barques as belonging to the "Lower Sandstone or Graywack Group" in his first annual report on the geology of Michigan. Houghton (1838, p. 279) also gave a brief account of the sandstone quarries at Jonesville and Napoleon, Michigan. A year later, Houghton (1839, p. 400) stated that the sandstones in Calhoun County belonged to "the great carboniferous group of rocks."

The first attempt at a systematic account of the strata which included part of the Marshall formation was made by Bela Hubbard in 1840. The following year, Hubbard (1841, p. 553) presented a stratigraphic column of the rocks cropping out in the "organized counties of Michigan." Winchell (1869, p. 59) wrote of this work: "In his attempt to assign them to their proper stratigraphical position, Mr. Hubbard fell into singular errors, and introduced into the most elaborate account of the lower peninsula which was destined to be published for twenty years, a confusion of facts which rendered the geology of Michigan an enigma to every one who attempted to parallelize the rocks with those of surrounding States."

The only other geologist who wrote concerning beds of the Marshall formation before the advent of the Winchell papers was R. P. Stevens (1858, p. 262), who described five species of fossils from the beds at Battle Creek. Stevens assigned these strata to the Carboniferous.

Three years later the first of a series of discussions of the Marshall formation by Alexander Winchell was published. Winchell (1861, p. 84) briefly described 25 feet of reddish to reddish green, fossiliferous sandstones cropping out near the town of Marshall in Calhoun County and named these beds in the Marshall group, stating that they were Chemung in age. He was able to trace the strata

northeastward into Huron County and northwestward into Ottawa County. Winchell (1861, p. 89) designated the grayer, less firmly cemented sandstone overlying the Marshall group as the Napoleon group and placed the latter at the base of the Carboniferous system. In regard to the Napoleon group, he (Winchell, 1861, p. 90) stated that, "As a distinct formation, therefore, it has no satisfactory equivalent in surrounding States; and there is no reason, except its negative paleontological characters, for separating it from the Marshall Group."

Winchell was the recognized authority on these beds for 15 years, although some of his ideas on the age of beds in other states which he correlated with his Marshall group were considered to be wrong by James Hall (Winchell, 1869, p. 73).

In his second report on the Marshall, Winchell (1862a, p. 353), after examining fossils from the top of the "Huron group," lowered the base of the "Marshall group" to include the 14 feet of bluish gritstone in the vicinity of Pointe aux Barques.

After the publication of this report, Winchell devoted his efforts to a study of the paleontology and age of the "Marshall group" and of its supposed equivalents in other states (Winchell, 1862a, 1862b, 1863). He abandoned his Chemung classification in 1865 and expressed the opinion that there was a "hitherto unrecognized group of strata lying at the very base of the carboniferous system" which is represented by the "carboniferous conglomerate" of western New York (Winchell, 1865, p. 110). He suggested that the westward extension of these conglomerates included the Marshall group.

Four years later a comprehensive summary of the work done on the Marshall group and its "equivalents" was presented by Winchell in a paper which was divided into two parts for publication (Winchell, 1869 and 1870). He (Winchell, 1870, p. 415) concluded that this group was equivalent to the upper part of the Catskill group of New York. He (Winchell, 1869, p. 74) again altered the stratigraphic table by making the "Napoleon group" a member of the "Marshall group" and by dividing the Marshall into three members with a total thickness of 298 feet as follows.

<i>Marshall Group</i>	<i>Feet</i>
Napoleon sandstone	123
Marshall sandstone	160
Huron gritstone	15

Although Winchell consistently referred to the strata under consideration as the "Marshall group," no publications subsequent to those of Winchell's were found in which the term "group" is used with the Marshall. The term "Marshall sandstone" was employed by Lane in 1895 and had the most frequent usage until 1931. Since 1931 the term Marshall formation has been used in most publications.

Carl Rominger, who succeeded Winchell as State geologist of Michigan, discussed the Marshall rocks in his report on the Lower Peninsula (1876), but re-

fused to follow Winchell's nomenclature or classification of the beds. He referred to the strata as the "Waverly group" and included the present Coldwater in the group. He (Rominger, 1876, p. 98) described the sediments as being shore deposits and stated that, "The stratification often becomes discordant, and frequent changes in the material are induced by local influences; while in one place a shale bed forms, in another near by a sand-rock ledge may be accumulated. A comparison of the strata in different outcrops of the Waverly group will for these reasons rarely allow of an identification of certain beds, and often not even of their exact horizon in the series."

Later, however, Lane (1895, p. 19) concurred with Winchell's ideas and considered the Marshall as marking the time at which the geological history of Michigan became independent of that of adjacent states, "so that any parallel must be made paleontologically rather than stratigraphically."

Lane (1900), in his report on Huron County, began the present practice of separating the Marshall into two divisions, the lower Marshall and upper Marshall, and of making the term Napoleon synonymous with upper Marshall. He (Lane, 1900, p. 19) assigned a total thickness of 560 feet to the Marshall formation in Huron County and stated that the 260 feet of lower Marshall is a transition from the thick shale underlying the Marshall to the heavy sandstones of the Napoleon. Cooper (1906, pp. 154-55) agreed with this idea but wrote that in Bay County the lower Marshall is appreciably thicker and the upper Marshall much thinner than in Huron County.

Later, Lane and Seaman (1909, p. 82) described a westward thinning of the Marshall and explained it by earlier emergence in the southwestern part of the state than in the northeastern part.

In his report on Arenac County, Gregory (1912, p. 58) accounted for the upper Marshall sandstone as being deposited in a southward-retreating and open Paleozoic sea.

The first attempt at describing the history of Marshall time was made by Cook (1914 p. 64) in his discussion of the salt and brine deposits of Michigan. The main feature of this geologic history was the isolation of the Michigan basin during Marshall time. Cook suggested that the red shales of lower Marshall are seaward phases of the sandstones of upper Marshall.

In the same year, Smith (1914a) wrote the first comprehensive discussion of the possible oil and gas fields of Michigan. He (Smith, 1914a, p. 30) expressed the opinion that the lower Marshall sandstones of Huron County are replaced by sandy shales in the central part of the Michigan basin and that the bottom and top of the lower Marshall beds are generally marked by a red color.

The publication of Smith's report marked the end of what might be referred to as the first phase of publications concerning the Marshall formation. There followed a period of 15 years during which the Marshall is scarcely mentioned in geologic publications. Much information from subsurface studies was obtained during this period, and in 1929 the beginning of the recent series of discussions

regarding the subsurface character of the Marshall formation appeared. Problems of interest to the petroleum geologists such as key horizons within the Marshall and the nature of the upper and lower limits of the formation were the primary subjects.

Newcombe (1929, p. 207) started these discussions by stating that the red zones of lower Marshall exhibited no uniformity in the Saginaw oil field and were useless in that area as a mapping datum, but that the Napoleon sandstone had statewide value as a good correlation marker. Four years later, however, he (Newcombe, 1933, p. 82) wrote that the top of the Napoleon was eroded. According to Newcombe, this erosion gave rise to considerable surface relief and locally the entire formation may have been removed in the western part of the Michigan basin.

Publications following Newcombe's initial article are numerous and by many authors. The facts and ideas set forth in the publications are an integral part of the present conceptions of the stratigraphy of the Marshall formation and are discussed later in this report.

COLDWATER FORMATION

GENERAL FEATURES

The Coldwater formation consists of the gray and gray-blue shales underlying the Marshall formation in all parts of the Southern Peninsula of Michigan. At most places it rests on the black shale of the Sunbury formation, but at some localities, especially in western and southwestern Michigan, it directly overlies the Ellsworth green shale or the Antrim black shale.

Although division of the formation into smaller stratigraphic units in certain areas may be possible, no zones have been found which can be recognized in all parts of the state. However, the character of the Coldwater sediments changes noticeably from east to west. Two general types of Coldwater sediments are evident in Michigan: a western facies, consisting of 565-1,080 feet of shale, in many places calcareous, with some interbedded dolomites; and an eastern facies, characterized by siltstones and fine-grained sandstones interbedded with the shales. Red shales and siltstones are common in the upper sediments of the eastern facies. Gray shale is the predominant rock of the formation in all parts of Michigan with the exception of the extreme eastern edge, where sandstone and siltstone comprise the greater part of the section. More than 1,000 feet of gray shale with no distinctive lithologic changes are penetrated in some wells near the center of the state.

A redbed at the base of the Coldwater is the only zone within the formation that can be recognized in both the western and the eastern facies. This bed varies in thickness from a few inches to 40 feet. It is red dolomite or limestone on the west side of the state, especially in Oceana, Newaygo, and Muskegon counties, and red shale in Clinton, Saginaw, and Shiawassee counties and parts of adjacent counties in the eastern part of the state. At most places the bed occurs at the very

base of the Coldwater, but it may be as much as 30 feet or more above the base of the formation in some localities. The approximate areal distribution of these basal Coldwater red sediments, where they are continuous, is indicated in Figure 3. As the red zone is irregular in its occurrence in the northern part of the Southern Peninsula, no attempt is made to map its distribution in this area. Small isolated areas of it in Isabella, Midland, and Gladwin counties are not shown in Figure 3.

Overlying the basal red zone is a thick shale which is often described by drillers as "blue shale." The shale is gray, very fine-textured rock which may be bluish gray when wet. The thickness of this shale and the lithologic character of the sediments interbedded with the shale vary in different areas.

WESTERN FACIES

The Coldwater of the western half of the Southern Peninsula, here referred to as the western facies, contains several calcareous or dolomitic strata. Distinctive beds of dolomite are recognized in well cuttings at depths ranging from 150 to 750 feet above the base of the formation. Under the popular term "Coldwater lime," Hale (1941, p. 722) describes four types of dolomite occurring in the formation: (1) a speckled dolomite consisting of a gray dolomite matrix with embedded grains of light brown dolomite; (2) speckled dolomite with "pepperings" of glauconite; (3) crystalline dolomite with "pepperings" of glauconite; and (4) crystalline dolomite with no glauconite. By means of a map, she shows that the speckled dolomite and glauconitic dolomite are generally confined to the western margin counties of the state. She (Hale, 1941, p. 723) states, "Eastward the dolomite is crystalline rather than speckled, although it occurs at about the same horizon and contains a little glauconite. Farther east and especially north the crystalline zones are common throughout the Coldwater gray shale section and indicate no definite horizon." In addition to the crystalline dolomite, shaly dolomite and dolomitic shale are present in the Coldwater near the center of the state. Although the thicknesses and stratigraphic positions of the various dolomites differ greatly, the dolomites are concentrated near the center or in the upper part of the formation. Fossil fragments are common in these dolomites.

Lithologically, the upper Coldwater shales in the western half of the state are identical with the lower shales of the formation. The top of the Coldwater formation is relatively easy to determine because the lithologic difference between the gray Coldwater shale and the Marshall red and tan sandstones is marked.

The lateral change from the western dolomitic sediments to the eastern silty and sandy deposits is gradational. The siltstone beds nearest the western facies sediments are commonly very dolomitic. It is possible, however, to draw a line separating the general area in which definite siltstones are recognized from the general area in which non-silty dolomitic sediments are present (Fig. 3). This demarcation between the eastern and western facies coincides approximately with a 1,050-foot isopach line of the Coldwater. Although the thickness of the

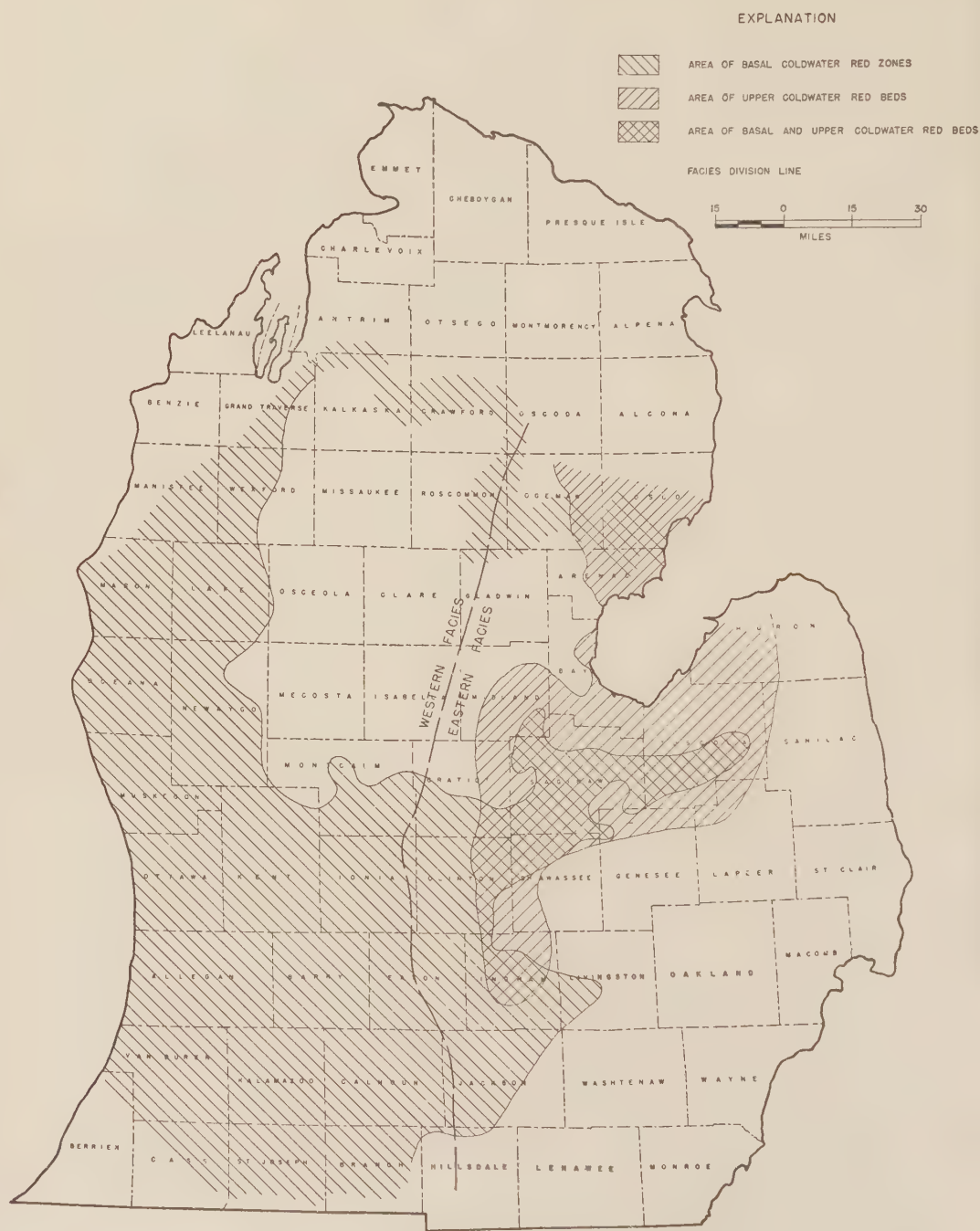


FIGURE 3
DISTRIBUTION OF LITHOLOGIC FACIES OF COLDWATER DEPOSITION

FIG. 3.—Distribution of lithologic facies of Coldwater deposition.

Coldwater ranges from 565 to 1,100 feet in the state, it apparently is not less than 1,000 feet and nowhere greater than 1,060 feet along this facies demarcation.

A common feature of the western facies of the Coldwater formation is the prominent thinning of the sediments from the center to the western margin of the state. A thickness of nearly 1,100 feet is revealed by several wells in Ts. 5-6 N., in Clinton County. From this area westward into Oceana County the Coldwater decreases in thickness more than 500 feet. The thinnest section obtained from well-sample examinations is 565 feet in T. 13 N., R. 16 W., Oceana County. Although these thicknesses are the two extremes, where the top and base of the formation are easily identified, similar thinning of the Coldwater occurs west of the area between Crawford and Calhoun counties. The 1,080 feet of Coldwater measured in eastern Roscommon County thins to 700 feet in Wexford County, 40 miles west.

A slight amount of southward thinning of the Coldwater formation toward the outcrop area is indicated. Thinning in this direction is much less than toward the west. The thickness of the Coldwater in Jackson County is 100-150 feet less than it is in Clinton County 50 miles north. An isopach line representing a thickness of 1,000 feet would extend east and west through the central part of Calhoun County and the northern part of Jackson County. It would maintain a dominantly north-south extent elsewhere in the state.

Thinning is not perceptible from the center of the state toward the area in which Coldwater shale underlies the glacial drift on the north side of the state. The most northern well from which samples are available is in the eastern margin of Kalkaska County (well 1, Fig. 4). A total of 925 feet of Coldwater was penetrated in this well. Wells drilled 30-60 miles south have approximately the same thickness of Coldwater.

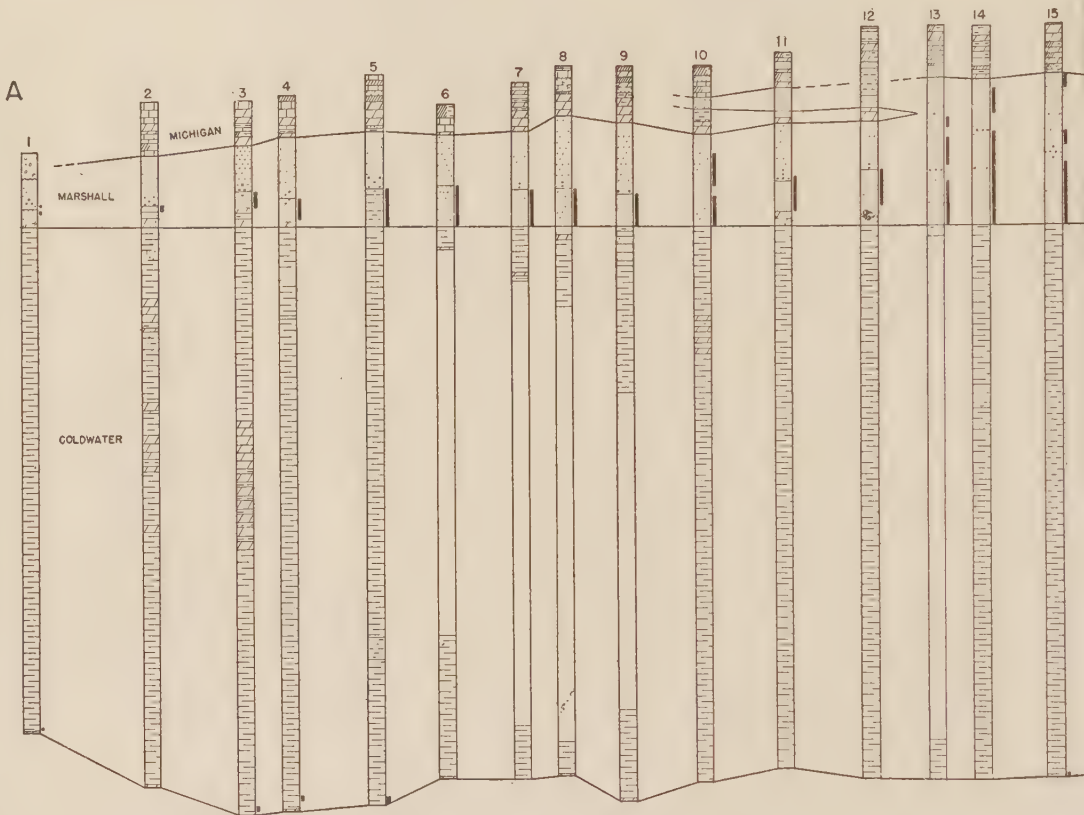
EASTERN FACIES

The eastern facies of the Coldwater formation presents a more complex stratigraphic problem that does the western facies. Although the lower limit of the formation is easily identified in well cuttings, the top is poorly defined due to the similarity of the sandy and silty sediments in the upper part of the Coldwater formation to beds in the lower part of the Marshall formation.

In the central part of the Michigan basin the basal Marshall strata are either extremely fine-grained red shaly sandstone or soft red silt ranging in thickness from 40 to 100 feet and occurring 100-130 feet below the top of the Marshall formation. East of central Michigan, within the limits of the eastern Coldwater facies, lithologically identical beds are intercalated with gray shales as far as 500 feet below the top of the Marshall formation. This occurrence led several writers (Cooper, 1906, p. 155; Carlson, 1927, p. 962; Newcombe, 1933, p. 57; Pringle, 1937, p. 22) to conclude that the deposits are lower Marshall in age and correlative with the 560 feet of Marshall sediments reported by Lane (1900, p. 22) in Huron County. This correlation implies a thickening of the

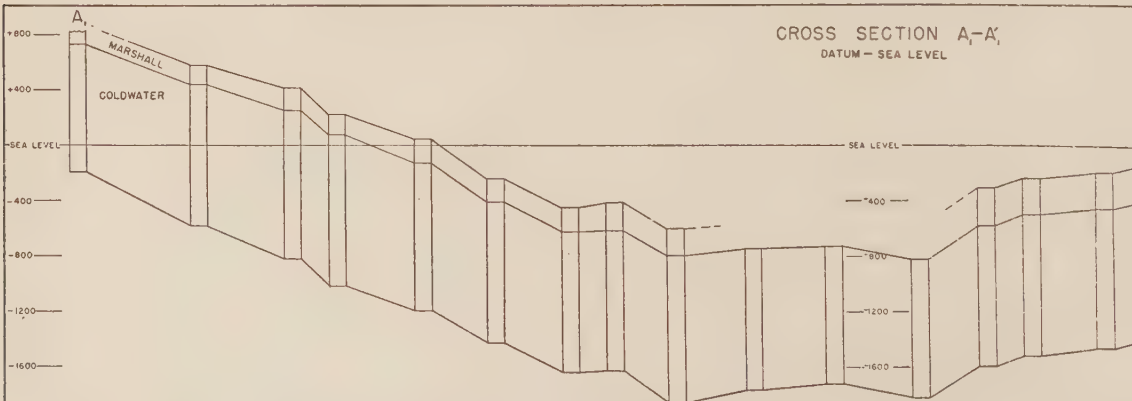
CROSS SECTION A-A'

DATUM - BASE OF MARSHALL



CROSS SECTION A-A'

DATUM - SEA LEVEL



FIGURE

FIG. 4.--Cross section

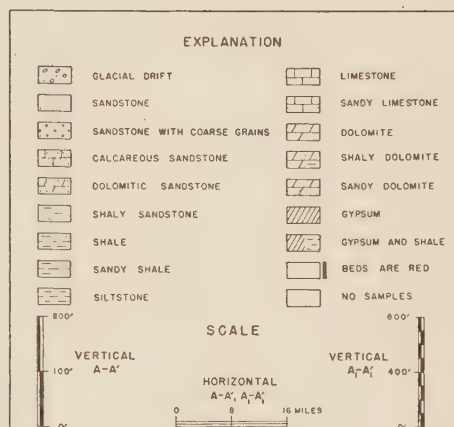
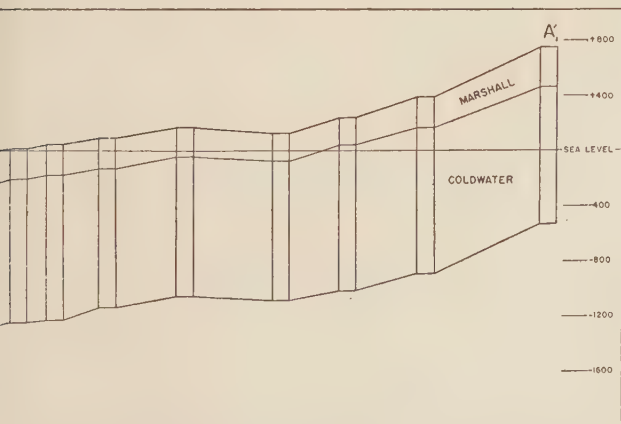
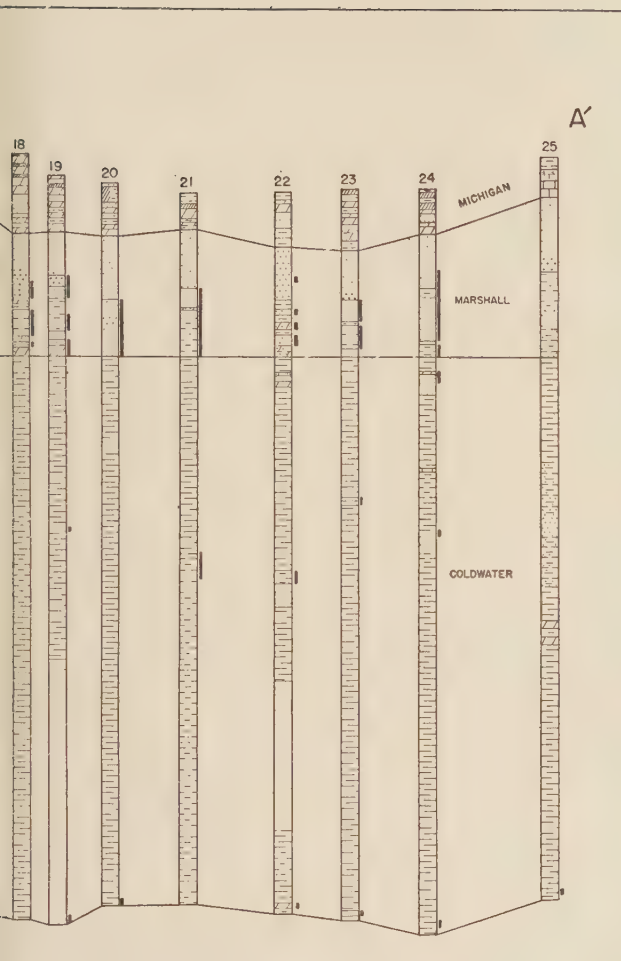
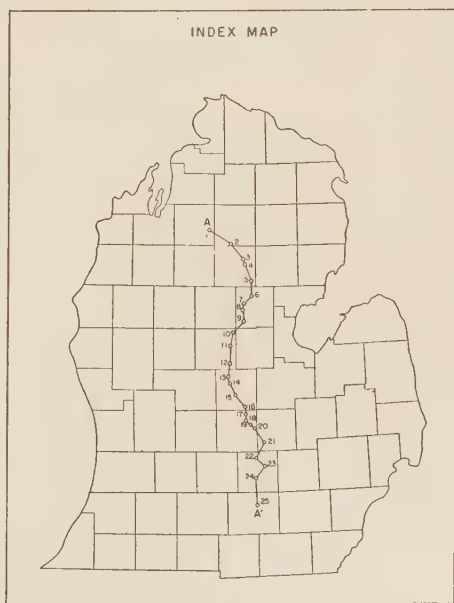


TABLE OF WELLS				
NO.	TWP. RNG.	COUNTY	COMPANY	FARM
1	16 26N 3W	KALASKA	GRAYLING DEV. CO.	STATE 1
2	33 25N 3W	CRAWFORD	COME OIL DEV. CO.	LUNDGREN 1
3	2 23N 2W	ROSCOMMON	SUN OIL CO.	SALLING HANSON CO. TR 1
4	26 23N 2W	ROSCOMMON	FRANKLIN PET. DEV. CO.	ST. HELEN 1
5	9 21N 1W	ROSCOMMON	GRALE OIL CO.	HALESTRO RESERVE INC. 1
6	33 20N 1W	GLADWIN	E. W. COLLINS	SUTER 1
7	22 19N 2W	GLADWIN	SMITH PET. CO.	SMITH & DOW 1
8	10 18N 2W	GLADWIN	SUN OIL CO.	CAMERON, JR. 1
9	11 17N 2W	GLADWIN	M. R. WHITEHILL	SPICER 1
10	11 16N 3W	ISABELLA	SOCOMY VACUUM OIL CO.	CAMPBELL 1
11	26 15N 3W	ISABELLA	M'CLANAHAN OIL CO.	DEMSKI 1
12	16 15N 3W	ISABELLA	H. E. BELL	NILSON 1
13	20 15N 3W	GRATIOT	K. B. MONTGOMERY, TR.	RAYCRAFT 1
14	9 11N 3W	GRATIOT	RED-MAN OIL CO.	DUCKWORTH 1
15	13 10N 3W	GRATIOT	CARTER COAL CO.	HIRSHMAN 1
16	26 8N 2W	GRATIOT	GULF REFINING CO.	LYON 1
17	12 8N 2W	CLINTON	GRALE OIL CO.	SOMMERVILLE 1
18	36 8N 2W	CLINTON	C. W. TEATER	HOLBROOK 1
19	8 7N 1W	CLINTON	C. W. TEATER	WALKER 1
20	25 7N 1W	CLINTON	STORK OIL	PARKER 1
21	1 0N 1E	SHIAWASSEE	DAN-ELS	CRAWFORD 1
22	23 4N 1W	INGHAM	KALADON DRILLERS INC.	SCHUBEL 1
23	16 3N 1E	INGHAM	COLVIN, JR.	GLASER 1
24	23 2N 1W	INGHAM	DARKE BROTHERS	ROYSTON 1
25	1 2S 1W	JACKSON	FISHER ET AL	CLARKE 1



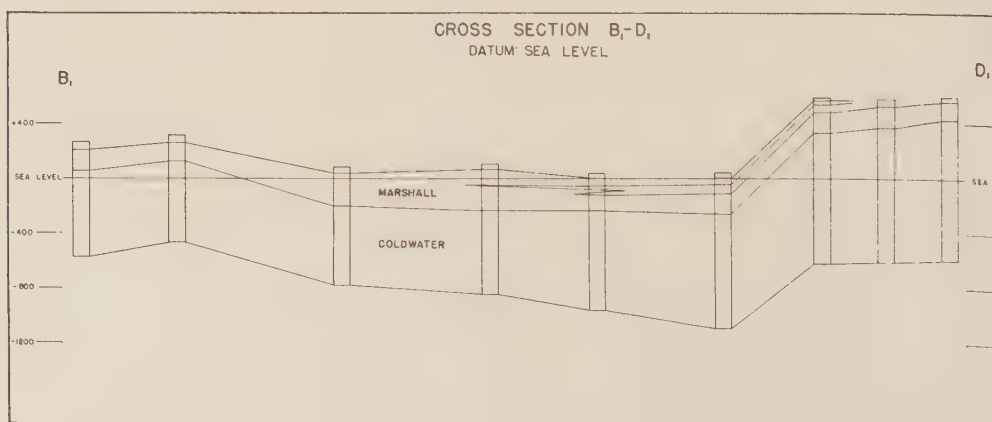
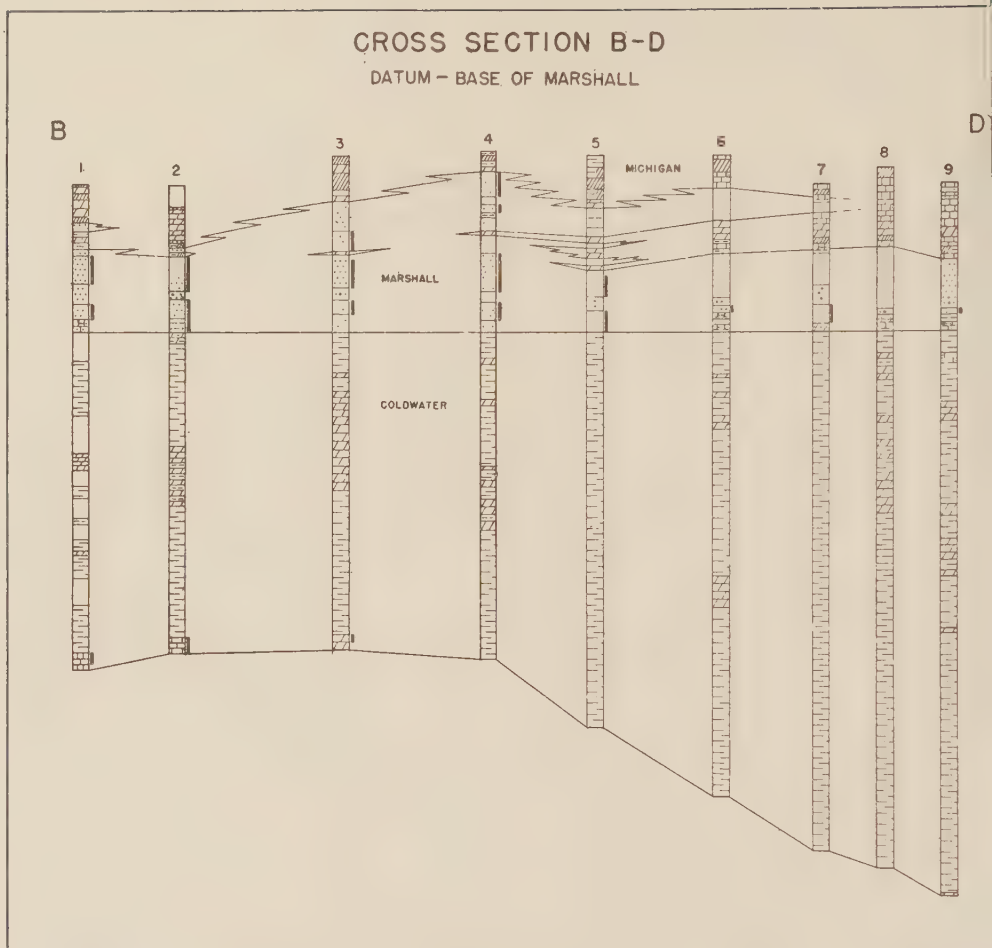
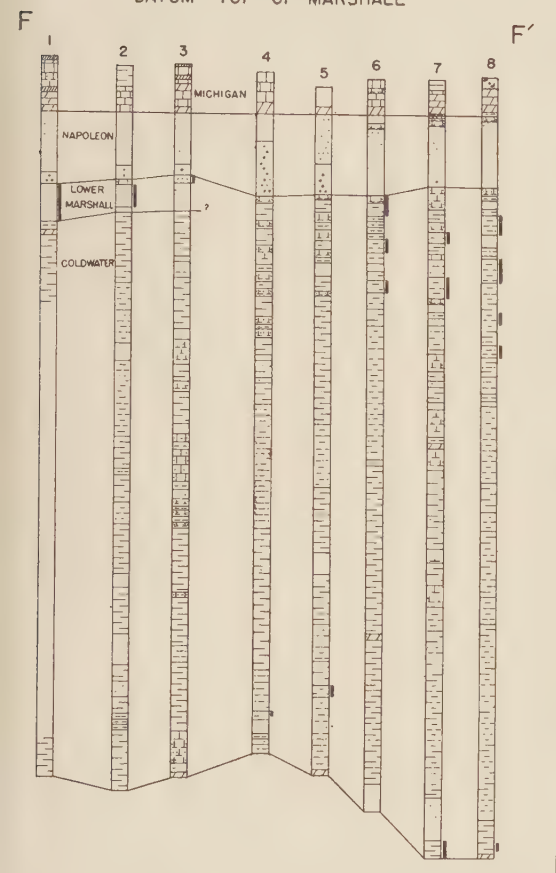


FIG. 5.—Cross

CROSS SECTION F-F'

DATUM - TOP OF MARSHALL



EXPLANATION

	GLACIAL DRIFT		LIMESTONE
	SANDSTONE		SANDY LIMESTONE
	SANDSTONE WITH COARSE GRAINS		DOLOMITE
	CALCAREOUS SANDSTONE		SHALY DOLOMITE
	SHALY SANDSTONE		SANDY DOLOMITE
	SHALE		GYPSUM
	SANDY SHALE		GYPSUM AND SHALE
	DOLOMITIC SHALE		RED BEDS
	SILTSTONE		NO SAMPLES

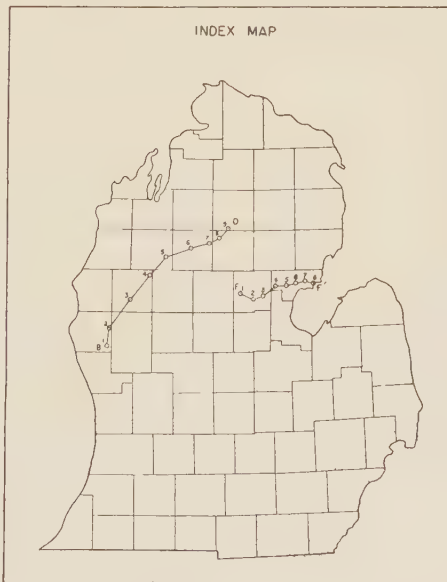
SCALE



TABLE OF WELLS

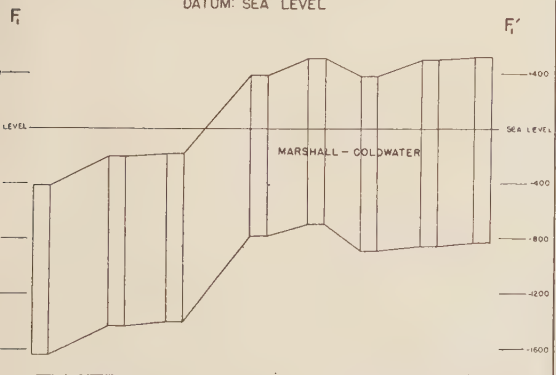
Section B-D							
No.	Sec.	Twp.	Rng.	County	Company	Farm	
1	16	13N	16W	Oseana	Reed Oil	W. E. Lewis #1	
2	24	15N	16W	Oseana	Johnson Oil Refining	Sippy #2	
3	25	18N	13W	Lake	R. B. Tashlyn	Cashion et al #1	
4	11	20N	11W	Lake	P. J. Bates, et al	W. Kellogg #1	
5	28	22N	2W	Wazford	Marble-Cove Oil	Smith #1	
6	26	23N	7W	Missaukee	Boyer Oil	S. Schetsenhelm #1	
7	11	23N	2W	Missaukee	Sun Oil	State-Enterprise #1	
8	26	24N	4E	Shoconung	Tr. R. D. Kirkham	William West #1	
9	33	25N	2W	Crawford	Dome Oil	S. Lundgren #1	
Section F-F'							
No.	Sec.	Twp.	Rng.	County	Company	Farm	
1	10	18N	2W	Gladwin	Sun Oil	A. Cameron, Jr. #1	
2	25	18N	1W	Gladwin	Ozell, et al	B. Card #1	
3	19	18N	2E	Gladwin	W. E. Ross, Tr.	C. W. Binson #1	
4	21	19N	3E	Arenac	D. Rayburn	John Fox #1	
5	15	19N	4E	Arenac	Central Drilling	Fiske #1	
6	8	19N	5E	Arenac	R. D. Mough	Clyde Stevens #1	
7	6	19N	6E	Arenac	C. W. Tester	B. A. Witty #1	
8	18	19N	7E	Arenac	Ward Oil	Daisy Petty #1	

INDEX MAP



CROSS SECTION F-F'

DATUM: SEA LEVEL



s BD and FF'.

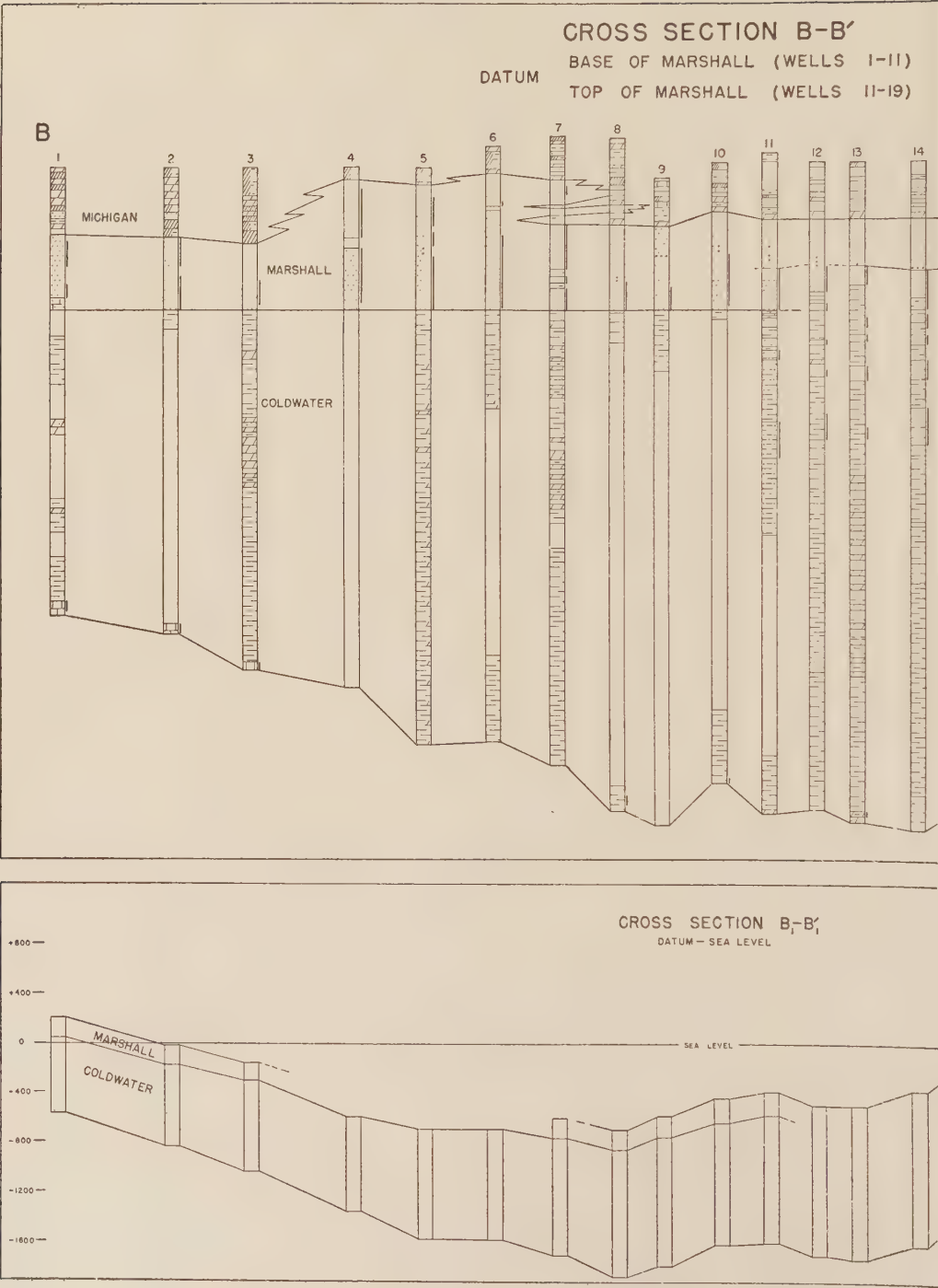
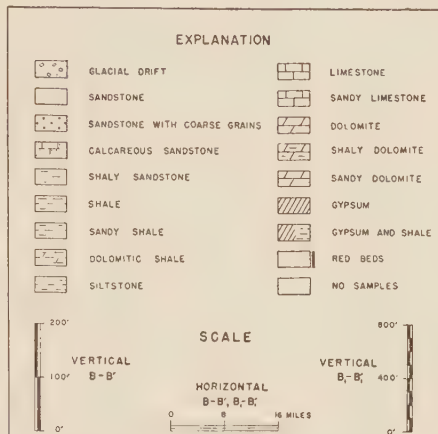
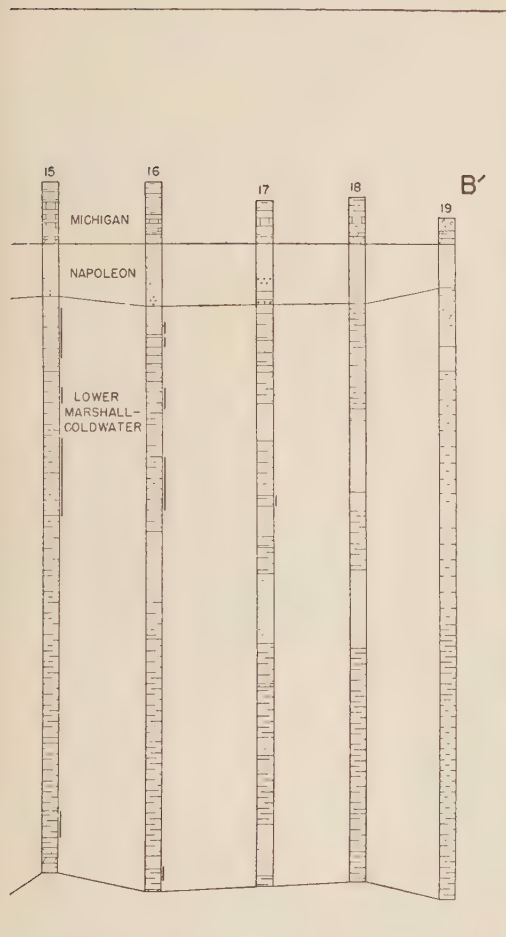
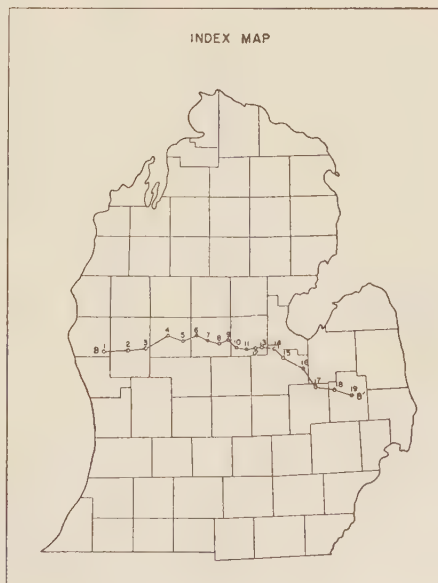
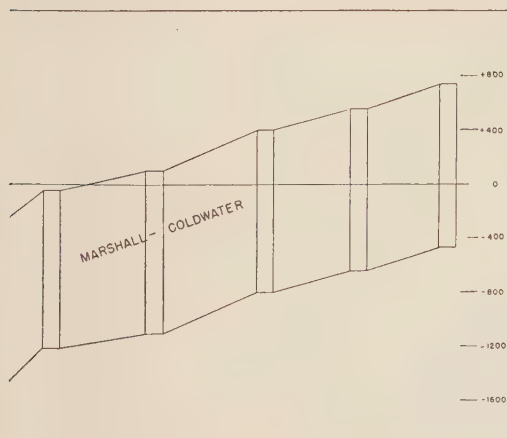


FIG. 6.—Cross section BB'.



No.	Sec.	Twp.	Rng.	County	Company	Form
1	18	13N	15W	Oceana	Reed Oil	W. H. Lewis #1
2	12	13N	13W	Hewago	Hewago Gas & Oil	Sates #1
3	3	13N	11W	Hewago	Turner Petroleum	Seaton #1
4	25	15N	9W	Manistota	Taggart Bros., Inc.	Tom Lintemuth #32
5	17	14N	7W	Manistota	Goli, Graves et al	M. Reta #1
6	34	13N	6W	Isabella	Pure Oil	J. W. Murray #1
7	14	14N	5W	Isabella	C. W. Tester	Stella Gray et al #1
8	26	14N	4W	Isabella	J. D. Gabel	J. W. Kennedy #1
9	14	14N	3W	Isabella	J. B. McCandless	Bufford #1
10	3	13N	2W	Midland	Pure Oil	Bond-Hoot #20
11	10	13N	1W	Midland	Pure Oil	John Mitchell #1
12	11	13N	1E	Midland	McClanahan Oil	John Brooks #1
13	9	13N	2E	Midland	Weller & Daper Oil	Heppensall #1
14	15	13N	3E	Saginaw	A. H. Weber, Tr.	Kirchner #1
15	10	12N	4E	Saginaw	Garr & Janssine, Tr.	M. Laurence #1
16	10	11N	6E	Saginaw	Goli, Graves et al	J. F. Mosener #1
17	11	9N	7E	Genesee	A. L. Williams	G. Totten #1
18	27	9N	9E	Lapeer	Smith Petroleum	Dep. Liq. Corp. #1
19	17	8N	11E	Lapeer	Einnekeleik Land	James Watson #1



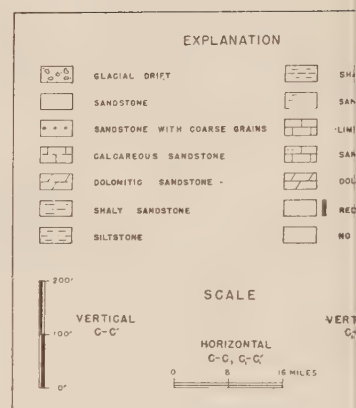
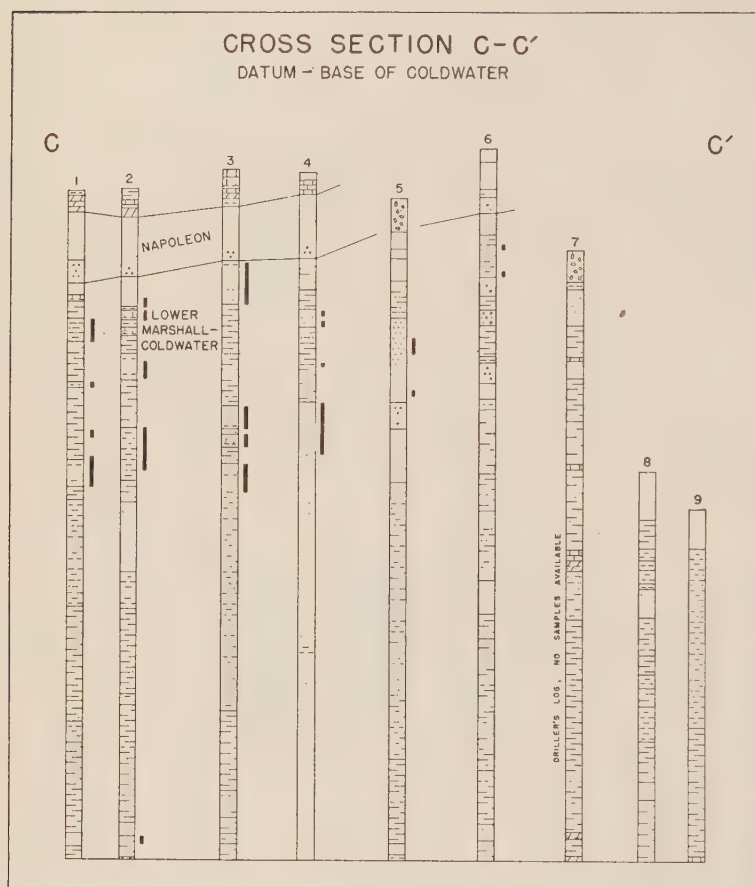


TABLE OF WELLS
Section C-C'

No.	Sec.	Twp.	Rng.	County	Company
1	36	11N	8E	Saginaw	Bridgeport Oil & Gas Dev't.
2	10	11N	8E	Saginaw	Gill, Graves & Bechling
3	8	12W	8E	Tuscola	W. P. Wieschers
4	5	13W	8E	Tuscola	Gulf Refining
5	16	13W	11E	Tuscola	Shull Oil
6	32	15W	12E	Buren	Pacific Exploration
7	27	16W	13E	Buren	C. W. Taiter
8	28	17W	14E	Buren	Jordan Oil
9	1	17W	14E	Buren	L. D. Henderson

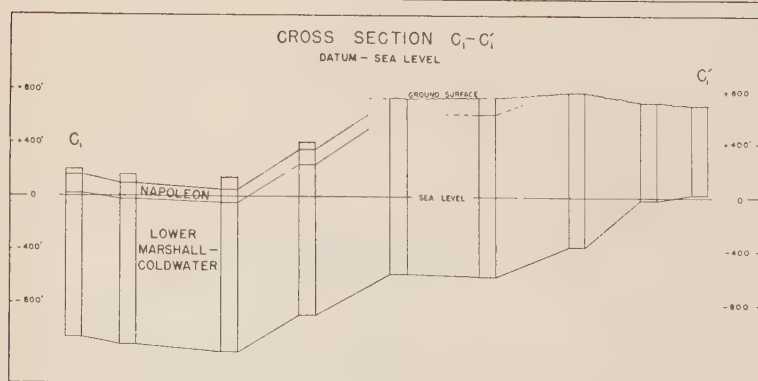


FIGURE 7
FIG. 7.—Cross section CC'.

Marshall amounting to more than 100 per cent from the west side of Michigan to the central and eastern part of the state. Data from more recent drilling have caused many of the petroleum geologists in Michigan to correlate the lower redbeds with the Coldwater formation. A thorough investigation of the Coldwater stratigraphy in eastern Michigan is therefore necessary to determine the Coldwater-Marshall relationship and to account for the 560 feet of Marshall beds assumed to be present in Huron County.

The general extent of the eastern and western facies of the Coldwater is outlined in Figure 3. East of the facies division line, wells penetrating the Coldwater formation show varying amounts of extremely fine-grained sandstone and siltstone interbedded with the Coldwater shale. The nature of the Coldwater and Marshall sediments in the eastern part of the state is shown on three cross sections. The most northern one, cross section *FF'* (Fig. 5), extends from the western side of Gladwin County to a well drilled within 2 miles of the northwest shore of Saginaw Bay in Arenac County. A general increase in the quantity of siltstone and sandstone from west to east is one of the most striking features of the section. The eastern half of section *BB'* (Fig. 6) extending from Midland to Lapeer County again illustrates an increasing amount of these clastics toward the east. Although the easternmost wells in the two sections are more than 65 miles apart, the lower Marshall-Coldwater sediments in each well are less than 20 per cent shale. A third cross section *CC'* (Fig. 7) extending from the central part of Saginaw County northeastward into Huron County does not show the eastward sandstone development as well as the other two sections. All of the wells illustrated in this section contain a large amount of siltstone and sandstone in the Coldwater-lower Marshall sequence.

A fair representation of the Coldwater and Marshall beds in the eastern half of the state is given by these three cross sections. Examination of the sections reveals the limitations of general statements which are applicable over the entire area regarding the stratigraphy. The stratigraphic position of the silty and sandy beds is not constant. They may occur in the basal 100 feet of the Coldwater formation (Shiawassee, Genesee, Bay, and Arenac counties) or at any stratigraphic level in the succeeding 1,000 or more feet of Coldwater-lower Marshall sediments. In Gratiot County they appear to be restricted to the middle part of the formation, but in Saginaw County, the adjacent county on the east, they occur at various stratigraphic levels throughout the section. Correlation of individual beds is difficult and in many places impossible with the data available.

Although red colors are uncommon in the siltstones adjacent to the dolomitic facies of the Coldwater, they occur from 6 to 15 miles east of the Coldwater facies division line (Fig. 3). The areal distribution of the redbeds is indicated in Figure 3. A question may arise concerning the western extent of these redbeds in Figure 3, as the lower Marshall of central and western Michigan is commonly characterized by red sediments. Examination of the north-south cross section

AA' (Fig. 4) clarifies this point. Wells 19-24 in the section show the initial occurrence from west to east of the red siltstones and sandstones several hundred feet below the top of the Marshall. The red zones illustrated in the section average 20 feet in thickness and are 600-750 feet above the base of the Coldwater gray shale, which is more than 1,000 feet thick in this area. Wells drilled a few miles west of this section penetrate an almost identical thickness of Coldwater, but no redbeds occur below the uppermost gray shale of the Coldwater, which lies directly under the Marshall formation. It is apparent from their stratigraphic position that these red zones are well within the limits of the Coldwater. They are overlain by 250-300 feet of typical Coldwater shale with a few interbedded siltstones and sandstones characteristic of the eastern facies. It is the westward extent of these lower red zones that is shown in Figure 3. In the area east of section *AA'* (Fig. 4) redbeds become more common in the upper part of the Coldwater formation, and it is very difficult to separate the redbeds of the Coldwater from those of the Marshall.

The redbeds in the lower Marshall and upper Coldwater strata in central and east-central Michigan are predominantly red siltstones. Very fine-grained red sandstones are common, however, and red shale is penetrated in some wells. The occurrence of red sediments from Midland County to Lapeer County is illustrated in the eastern part of cross section *BB'* (Fig. 6). The section reveals 3-5 red zones at different stratigraphic levels from 90 to 500 feet below the top of the Marshall sandstone. The highest and lowest of these zones are the most persistent. The uppermost red zone, consisting of 40-100 feet of red sandstone and siltstone at the base of the Napoleon sandstone, is equivalent, in part at least, to the lower Marshall beds. The lowermost red zone consists of 50-75 feet of red siltstone and shale occurring 400-500 feet below the top of the Marshall. This zone extends farther eastward than any other red zone in the Marshall or Coldwater formations. Between the upper and lower red zone, one to three beds of red siltstone and sandstone, as well as a few gray beds of the same lithologic character, are interbedded with gray shale.

It is apparent from an examination of cross section *BB'* that the Coldwater-Marshall contact is very indefinite east of central Midland County. It has been shown that the lower red siltstones grade laterally into Coldwater gray shales in the central part of the state. A separation of the higher red zones into those of Coldwater age and those of lower Marshall age would not be justified. There appears to be no lithologic feature that can be traced for any appreciable distance which could be used as the basis for the separation. The red zone directly underlying the tan Napoleon sandstone in this area must be partly equivalent to the red lower Marshall strata which are clearly defined in western Midland and Isabella counties. The fallacy in using the base of this uppermost red zone as a criterion for the Coldwater-Marshall division in eastern Michigan is illustrated by wells 14, 15, 16, and 17 in cross section *BB'* (Fig. 6). It is apparent that the 115 feet of dark red siltstone in well 15 grades laterally into red and tan sandstones

and gray shales. Similar conditions are illustrated in the other cross sections that extend into the area of Coldwater-Lower Marshall redbed occurrence (section *FF'*, Fig. 5; section *CC'*, Fig. 7).

Toward the margin of the area in which the Coldwater-lower Marshall redbeds occur the number and thickness of the red zones diminish. The occurrence of the redbeds near the western margin has already been discussed. Very little information is available concerning the northern extent of the red sediments other than the restriction of the lower red zones to the area east of the anticlinal fold in Arenac and Ogemaw counties (cross section *F'*, Fig. 5). There are no redbeds in the Coldwater-Marshall strata on the crest of this anticlinal area, although red colors occur at the west in the lower Marshall sediments in the region where the Marshall and the Coldwater formations can be separated.

There is a gradual disappearance of the red zones toward the eastern and southern margins of the area in which they occur. Cross section *BB'* (Fig. 6) illustrates the decrease and disappearance of red color from the sediments. The only red zone recognized in Genesee and Lapeer counties is the lowest one, which is approximately 25 feet thick and occurs 400–500 feet below the top of the Marshall. This zone is absent east of the extreme northwest part of Lapeer County and no red sediments are found in the entire Coldwater-Marshall sequence of rocks.

The disappearance of the red color from the Coldwater-lower Marshall strata does not simplify the separation of the two formations in the eastern part of the state. The interval between the Napoleon sandstone and the Sunbury black shale is composed of 1,100–1,300 feet of interbedded sandstone, siltstone, and shale. There is no lithologic unit which may be used as a basis for separating the two formations in their subsurface occurrence. The individual beds of both coarser and finer clastics are not continuous and appear to grade laterally into one another. Attempts to establish a subsurface stratigraphic division between the Coldwater and Marshall formations from the data now available may lead to misinterpretations of the stratigraphy in this area.

The thickness of the Coldwater in the eastern part of the Lower Peninsula is not measurable due to the indefinite nature of the top of the formation. However, the examination of the interval from the top of the Marshall to the base of the Coldwater is of interest. With the exception of eastern Arenac, eastern Ogemaw, Iosco, and Huron counties, this interval varies less than 90 feet in all counties embracing the eastern Coldwater facies north and east of Clinton County. In the extreme northwest township of Saginaw County there is a total Coldwater-Marshall thickness ranging from 1,200 to 1,220 feet. In Lapeer County, 60 miles southeast, 1,190–1,220 feet are recorded. The interval amounts to 1,240 feet in the southeast corner of Roscommon County, 60 miles north of Saginaw County. The minimum thickness observed within the area indicated was 1,160 feet in the western part of Saginaw County.

The Coldwater-Marshall thickness increases markedly not far east of north-

central Arenac County and western Ogemaw County (section *FF'*, Fig. 5). Wells drilled in the north-central part of Arenac County penetrate 1,200–1,240 feet of Coldwater-Marshall sediments. Twelve miles east, 1,350 feet are drilled. Less than 10 miles farther east, beyond the extent of section *FF'*, this interval approaches 1,500 feet. These sediments vary from 1,320 to 1,470 feet in thickness in Iosco County northeast of Arenac County. It is shown in the discussion of the Marshall formation that the Napoleon sandstone is nowhere greater than 160 feet and nowhere less than 90 feet in thickness in this area. The eastward thickening is therefore a feature of the Coldwater-lower Marshall sediments.

CHARACTER OF DEPOSITIONAL BASIN

Several conclusions regarding the nature of the basin in which the Coldwater sediments were deposited may be made from the data now available. The westward thinning of the sediments and the gradual lithologic change from dolomites and shales in the west to shale, siltstone, and sandstone in the east are strong evidence of an eastern source of sediments. The rather abrupt thickening of the Coldwater-lower Marshall deposits from Arenac and western Ogemaw counties into Iosco County may indicate a localization of the main source of sediments northeast of this area.

Some information pertaining to the size of the area of deposition is afforded by the small amount of thinning on the south, the absence of thinning on the north, and the lithologic character of the western sediments. The absence of north-south thinning implies an original extent of the Coldwater sediments far beyond the present boundary of the formation. The absence of clastics other than fine-textured shale, and the increasing development of chemically precipitated sediments in the western margin of the state suggest that these sediments were deposited an appreciable distance from the former western limit of the Coldwater deposits.

Examination of the several cross sections included in this report reveals a thinning of the Coldwater strata over anticlinal folds in the Michigan basin. This relationship was suggested by Newcombe (1933, p. 81). A thinning of the combined Coldwater-lower Marshall beds over the anticline in Arenac County is shown in section *FF'* (Fig. 5). The absence of the top of the Coldwater on the Howell anticline in the southeastern part of the state makes it difficult to determine the amount of thinning of the formation over the structure. There is, however, a thinning toward the anticline from the north, west, and east. Thinning over the smaller and more poorly defined anticlines in the central and western parts of the Michigan basin is indicated, but is of such small magnitude that it may be questioned. This thinning of the Coldwater over the larger anticlines and possibly over the smaller ones indicates that these folded structures antedate Coldwater sedimentation. Ballard (1938, p. 1,548) reports a personal communication from C. C. Addison in which the latter suggests a thinning of the basal Mississippian beds over oil-producing structures in Allegan County.

The marine sedimentation basin in which the Coldwater sediments were deposited appears to have occupied a large area comparable with the size of the basins in which older Paleozoic sediments in Michigan were deposited. The basin contained topographic irregularities of varying sizes due to the expression of folding in the older rocks on the sea floor. Sediments entering the basin from the east consisted of sands, silts, and muds. Variations in the volume of these sediments and in the current and wave action within the eastern part of the depositional basin caused an interfingering of these clastics as they were deposited. Toward the close of Coldwater time some of the streams entering the basin apparently flowed from an area in which red ferruginous sediments had originated. These red sediments were carried into the basin and were deposited in an interfingering sequence similar to that of the other Coldwater deposits.

Fine muds were settling out of the more open sea on the west beyond the area where the coarser clastics were being deposited. The precipitation of carbonate deposits occurred at intermittent times in the quieter and deeper waters. They became more common still farther west where less mud was transported by the water. The influence of a western landmass on the present Coldwater deposits appears to have been negligible.

MARSHALL FORMATION

OUTCROPS

General area.—The Marshall formation is covered with glacial drift in most of the outcrop area and only few natural exposures of the sandstones are found. All of the larger exposures in the southern part of the state are in old quarries, most of which were abandoned long ago. Surface appearances of the Marshall occur in Hillsdale, Jackson, and Calhoun counties in southern Michigan, Ottawa County in southwest Michigan, and in eastern Tuscola, western Sanilac, and northern Huron counties comprising the "Thumb" area of eastern Michigan. The outcrops in Huron County are discussed separately from the other Marshall outcrops because they present a separate problem.

Hillsdale County.—The most southern exposure of Marshall strata in the state where more than 10 feet of section is exposed is about 1 mile northeast of Osseo, in the northwest corner of Sec. 4, T. 7 S., R. 2 W., in Hillsdale County. The outcrop consists of 20 feet of thin-bedded, very fine-grained argillaceous sandstone. The sandstone is buff to greenish buff in color in the upper part of the exposure and rust brown in the lower part. Numerous fossils are in the talus.

North and west of Osseo, old quarries at Hillsdale and Jonesville provide outcrops of Marshall strata. The quarry at Hillsdale is within the city limits, in the SW. $\frac{1}{4}$ of Sec. 22, T. 6 S., R. 3 W. Although more than 25 feet of strata was exposed in this quarry many years ago, it has been filled in to such an extent that now less than 8 feet of bedrock is available for examination. The rock is an olive-green to buff, thin-bedded, very fine-grained sandstone.

The quarry at Jonesville is at the southern edge of the city limits on the east bank of an old mill race about 200 feet north of the mill pond. Thirty feet of tan to greenish gray, thin-bedded, very fine-grained sandstone is exposed. Fossils are present in the talus although they are not abundant.

A petrographic study was made of a sample of the sandstone exposed at Jonesville. More than 90 per cent of the sandstone is quartz. Other constituents, in order of their abundance, include chert, muscovite, biotite, and plagioclase



FIG. 8.—Abandoned quarry in Marshall sandstone at Stony Point, Jackson County, Michigan. Photograph by G. M. Ehlers.

feldspar. The sandstone contains minor amounts of chlorite, ilmenite, rutile, and zircon.

Several small and isolated exposures of Marshall strata are in the northern tier of townships in Hillsdale County. The most accessible are in a road cut 3 miles east of Litchfield in the SW. $\frac{1}{4}$ of Sec. 18, T. 5 S., R. 3 W., and in road cuts around Mosherville Station in Sec. 2, T. 5 S., R. 3 W. The beds at these localities consist of very fine-grained, olive-green to buff sandstone which is very similar in lithologic character to the strata at Jonesville and Hillsdale. However, 6 feet of sandstone exposed in a new pipe-line ditch $1\frac{1}{2}$ miles north of Jerome in the NW. $\frac{1}{4}$, NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 7, T. 5 S., R. 1 W., is lithologically very different. The rock is medium-grained, porous and friable sandstone which is light buff and grayish white in color.

The fine-grained, fossiliferous sandstones of Hillsdale County are generally



FIG. 9.—Quarry in upper Marshall sandstone at Napoleon, Jackson County, Michigan.

considered to belong in the lower Marshall strata. The medium-grained, non-fossiliferous sandstone near Jerome is more similar to the sandstone at Napoleon, 13 miles northeast, than to any of the other sandstones in Hillsdale County.

Jackson County.—The largest exposure of Marshall deposits in the state is in southern Jackson County at the abandoned Stony Point quarry (Fig. 8) southwest of Hanover in Sec. 31, T. 4 S., R. 2 W. The section is as follows.

SECTION OF MARSHALL STRATA EXPOSED AT STONY POINT IN SEC. 31, T. 4 S., R. 2 W.

	<i>Feet</i>	<i>Inches</i>
Sandstone, fine-grained, tan, very friable	16	
Sandstone, fine- to medium-grained, buff; contains some small, gray, lenticular "mud lumps"	10	
Sandstone, fine-grained, buff to brown; contains molds of pelecypods and goniatites coated with limonite		6
Sandstone, fine- to medium-grained, buff to brown, friable, micaceous	9	6
Sandstone, fine- to medium-grained, buff, massive; contains a few poorly preserved fossils	13	
	49	

The mineral composition was determined of a sample of the sandstone taken 5 feet above the base of the exposure. About 95 per cent of the rock is quartz, feldspar, and mica. The feldspar content of the sandstone varies from 5 to 10 per cent and is greater than that of the sandstone at Jonesville.

The Stony Point exposure probably belongs in the central part of the Marshall formation. Beds in the upper part of the Marshall crop out at Napoleon northeast

of this locality and sandstones in the lower part of the formation are in Hillsdale County on the south. Lithologically, the sandstone at Stony Point possesses characteristics common to both the coarser sandstones at Napoleon and the finer sandstones on the south.

Another good exposure of Marshall sandstone in Jackson County is in the quarries at the east edge of Napoleon, Michigan (Fig. 9). This is the type locality of the Napoleon sandstone described by Winchell (1861, p. 89). Winchell measured 75 feet of sandstone in the area of the quarries. Twenty-five years later, Rominger (1876, p. 80) recorded 50 feet of sandstone at the same locality. At the present time less than 20 feet of bedrock is exposed. It consists of medium-grained, friable, non-fossiliferous sandstone. The strata are very light buff on fresh surface but weather to medium-gray. The sandstone appears massive from a distance but on closer examination, particularly of the weathered surfaces, a series of thin beds are seen. This thin bedding makes it possible to quarry large flat blocks of sandstone 1-4 inches thick.

There is no noticeable change in the sandstone from the bottom to the top of the quarry. The sand grains are subangular to subrounded and do not have frosted surfaces. Quartz and chert are the chief constituents of the sandstone. Biotite and chlorite are common and minor amounts of tourmaline, ilmenite, and zircon are present. The feldspar content of the sandstone is very small.

Outcrops of Marshall beds elsewhere in Jackson County are rare. The formation is very close to the surface at several localities in the southern part of the country but no bedrock was observed.

Calhoun County.—The Marshall sandstone is very near the surface at many places along the Kalamazoo River Valley between Homer and Battle Creek in Calhoun County. The presence of several quarries along the river make this area the best in the state in which to study the Marshall strata.

Down the river from Homer, an abandoned quarry on the west river bank in the NE. $\frac{1}{4}$ of Sec. 20, T. 3 S., R. 4 W., reveals 22 feet of non-fossiliferous sandstone. The rock is the most coarsely grained Marshall sandstone exposed in southern Michigan. It is a porous, friable rock composed of medium to coarse sand grains and ranges in color from buff to grayish white. The sandstone is more massive than that at Napoleon.

The next outcrop west, near Morengo, is one of the few natural exposures of more than 5 feet of Marshall sandstone in southern Michigan. The outcrop is on the south bank of Kalamazoo River near the center of Sec. 30, T. 2 S., R. 4 W. Approximately 14 feet of small- to medium-grained, light tan to grayish white sandstone rises above the river flat. The lower 5 feet is mostly covered, but the remaining 9 feet is very friable, porous, massive sandstone showing some cross-bedding. A few feet of this sandstone is exposed in a road cut 1 mile south-east in Sec. 32 of the same township.

The quarry at Marshall, Michigan, from which Winchell (1861, p. 84) adopted the name of the Marshall formation, now furnishes much less section to examine

than it did in Winchell's time. Winchell described 25 feet of rock in 1861, whereas now only 9 feet is exposed. Undoubtedly 25 feet of sandstone is present, but most of it is covered. It is only due to recent quarry operations that the 9 feet is exposed. The rock is a fine-grained, olive-green to tan sandstone which is rather massive at the base and thin-bedded and platy toward the top. A few large flakes of muscovite are in the sandstone. Although a few pelecypods are present throughout the 9 feet, an abundance of fossils occurs in a bed of shaly, ferruginous sandstone 3 feet above the base of the exposed section. The extremely fossiliferous bed is soft on fresh surfaces and complete fossils can be obtained, but the bed becomes very hard after it has weathered a short time, and the collection of unbroken fossils is more difficult.

The mineral content of a sample of the sandstone taken one foot above the base of the quarry was determined. Quartz and chert are the most common minerals, comprising about 90 per cent of the sample. Biotite, feldspar, and fragments of mica schist are the other chief constituents. Minor amounts of ilmenite, chlorite, apatite, tourmaline, and calcite are likewise present in the sandstone.

Larger exposures of Marshall strata are along the Kalamazoo River between Ceresco and Battle Creek. A quarry on the north side of the river 1 mile west of Ceresco in the southwest corner of Sec. 24, T. 2 S., R. 7 W., provides the following section.

SECTION OF MARSHALL STRATA EXPOSED IN QUARRY IN SEC. 24, T. 2 S., R. 7 W.

	<i>Feet</i>	<i>Inches</i>
Sandstone, fine-grained, thin-bedded, argillaceous and hard	8	8
Sandstone, fine-grained, thin-bedded, argillaceous; contains thin bands of limonite molds of ostracods	10	
Sandstone, fine- to medium-grained, thick-bedded, tan; contains some large flakes of mica	5	
	23	8

The entire section is argillaceous as compared with the sandstone at Marshall. The argillaceous content makes it harder and better cemented. When crushed, the sandstone resembles light brown silt. Ostracods were the only fossils observed in the sandstone.

Two miles farther downstream, on the north side of the river in Sec. 15, T. 2 S., R. 7 W., is the abandoned Clark quarry. The north bank of Kalamazoo River between these two quarries seems to be composed largely of Marshall sandstone, but bedrock is seen in few places. The 22 feet of sandstone exposed in the Clark quarry is generally more coarse-grained than that at the Ceresco or Marshall quarries. The lower and more massive 12 feet consists of fine-grained sandstone with a few disseminated grains of medium size, but in the upper 10 feet coarser sand grains are more abundant. The sandstone ranges in color from olive-green to grayish tan.

A petrographic examination of a sample of this sandstone 13 feet above the base of the exposure shows a feldspar content much greater than that of other

Marshall sandstones in Michigan. Orthoclase, microcline, and varieties of plagioclase feldspar constitute at least 20 per cent of the grains in the sandstone. Approximately 75 per cent of the minerals are quartz and chert. Biotite, muscovite, fragments of mica schist, rutile, and zircon are the remaining constituents.

Marshall strata underlie a thin soil covering at several places in Battle Creek and are commonly exposed in excavations in the city. The bed of Kalamazoo River has been reported to be fossiliferous Marshall sandstone in the vicinity of the Kendall Street and the Emmet Street bridges. Although the fossiliferous beds were not seen, the following section was measured on the west bank of the river about 100 feet upstream from the Emmet Street bridge.

SECTION OF MARSHALL STRATA EXPOSED NEAR EMMET STREET BRIDGE,
BATTLE CREEK, MICHIGAN

	Feet	Inches
Sandstone, fine- to medium-grained, tan to gray, very friable, with some indications of cross-bedding	7	
Clay, gray, soft		6
Sandstone, fine- to medium-grained, greenish gray to tan; beds are 1-6 inches thick	2	
Sandstone, fine-grained, greenish gray	3	6
	13	

Ottawa County.—No exposures of the Marshall were observed between Battle Creek and Holland, Michigan. A quarry in Sec. 22, T. 5 N., R. 15 W., east of Holland and southeast of Waverly, marks the most northern and western surface occurrence of the Marshall formation in this part of the state. The quarry, which is as much as 40 feet deep in some parts, is now nearly filled with water. On the east side of the quarry 2 feet of gray to buff, fine-grained sandstone stands above the water level. The lower 6 inches is very fossiliferous, brown, ferruginous, fine-grained sandstone. The high content of iron oxide makes the rock very hard.

Slabs of sandstone taken from the lower parts of the quarry for building purposes were examined in the town of Holland. The sandstone is greenish tan, fine-grained, silty, and micaceous. A thin section of the rock was made and the mineral content determined. The constituents are essentially the same as in other fine-grained Marshall sandstones in southern Michigan. Feldspars comprise more than 10 per cent of the sample. Flakes of biotite and muscovite and fragments of mica schist also are present.

Tuscola and Sanilac counties.—Several exposures of upper Marshall (Napoleon) sandstone occur in northeastern Tuscola and northwestern Sanilac counties in the vicinity of the North Branch of Cass River. Gordon (1900, p. 12) estimated that about three-fifths of Sanilac County is underlain by Marshall sandstones. Rominger (1876, p. 78) reported outcrops of coarse-grained sandstone in the towns of Elkland and Novesta in Tuscola County and in the towns of Greenleaf and Argyle in Sanilac County. Most of the rock is thinly bedded, but in some places beds up to 3 feet in thickness occur between the thin-bedded deposits. Good exposures in Sanilac County are along the north bank of a small stream in the

northwest corner of Sec. 13, T. 14 N., R. 12 E., and in the northeast corner of Sec. 19, T. 13 N., R. 13 E. A sample of the sandstone from the village of Tyre in Sec. 1, T. 14 N., R. 13 E., Sanilac County, where upper Marshall beds reach the surface was sectioned for petrographic study. Quartz and chert comprise most of the sand grains. There are minor amounts of feldspar, zircon, ilmenite, biotite, muscovite, and apatite.

Some clues regarding the lithologic character of the beds immediately underlying the Napoleon medium- to coarse-grained sandstone were found near Argyle in Sanilac County in the northeast corner of Sec. 28, T. 13 N., R. 13 E. The rocks dredged out and dumped along the banks of a small stream at this locality consist of blue-gray shale and fine-grained, greenish brown sandstone. Among these rocks some fragments of conglomerate were found which are very similar to the "peanut conglomerate" of northern Huron County. Although no bedrock was definitely recognized, parts of the stream bed appeared to be blue-gray shale. Rominger (1876, p. 78) described beds of shale and fine-grained sandstone in bluffs along the side of Cass River in Sec. 7, T. 13 N., R. 12 E., Sanilac County.

SUBDIVISION IN SOUTHERN MICHIGAN

A division of the Marshall formation into two distinct members is very difficult in most parts of the state. The division in the area of outcrops has been based on the presence of fossils in the lower, fine-grained sandstones of lower Marshall and the absence of fossils in the upper, coarser-grained Napoleon sandstone. These criteria are of little aid in the division of the Marshall in subsurface work and are not applicable everywhere in the outcrop area. There are many feet of fine-grained sandstone exposed in Calhoun County in which fossils are exceedingly scarce. A few fossils are found in coarser-grained sandstones at Stony Point in Jackson County, although their occurrence in rocks of this type is not common.

The use of grain size to determine whether an outcrop is in the upper or lower parts of the Marshall is very questionable. Medium-grained sandstones are not entirely restricted to the upper part of the Marshall but may occur in the lower part of the formation interbedded with fine-grained sandstone. Conversely, fine-grained sandstones are not confined to the lower part of the formation, but occur interbedded with the more coarse-grained sandstones in the upper part of the Marshall, especially in the southwestern part of the state.

The variations in grain size are even more evident in the wells that penetrate a complete Marshall section a few miles basinward from the outcrop area. Cross section *GG'* (Fig. 10) illustrates the lithologic character of the Marshall formation in subsurface adjacent to the outcrop area in southern Michigan extending from Jackson County northwest into Ottawa County. The Coldwater-Marshall contact in this area is marked by a distinct change in lithology. The Marshall sediments overlying the Coldwater gray shale consist of fine-grained, tan sandstone and medium-grained, tan to white sandstone. Thin discontinuous lenses of gray

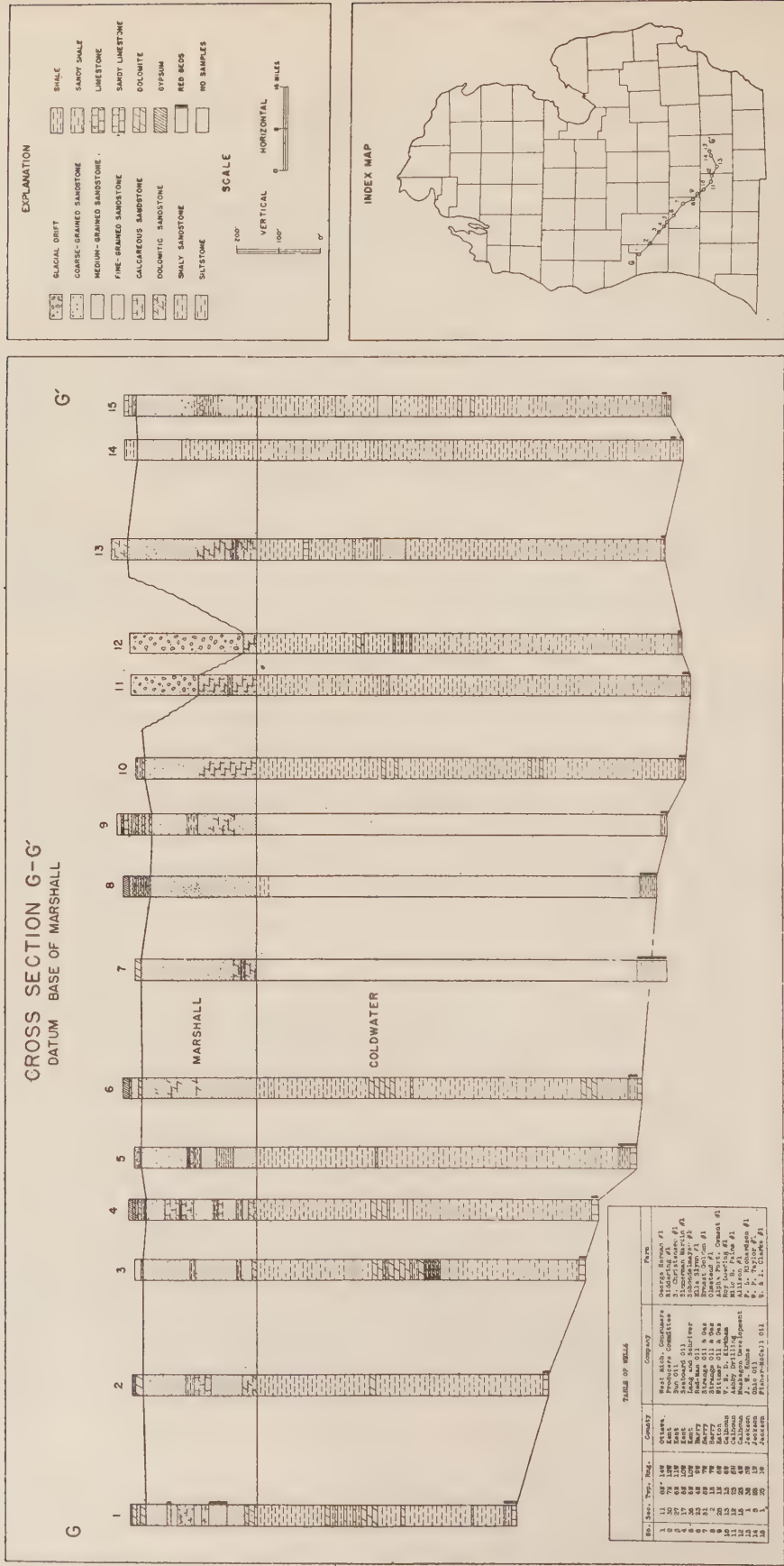


Fig. 10.—Cross section GG'.

shale occur at various stratigraphic positions within the Marshall formation in half of the wells illustrated in cross section *GG'*. The lowermost Marshall beds are fine-grained and commonly calcareous or dolomitic.

A well in north-central Calhoun County (well 9, cross section *GG'*, Fig. 10) contains a Marshall sequence very similar to that described by Winchell (1861, p. 139) from his examination of outcrops. The well penetrated 130 feet of medium-grained, white to tan, porous sandstone overlying 135 feet of grained, calcareous sandstone. This is an ideal section for dividing the formation into two members. The upper 130 feet closely coincides with the original description of the Napoleon sandstone and the lower 135 feet represents the lower Marshall sandstone. Unfortunately, however, the section is not typical of the Marshall formation. The wells in Eaton, Barry, Kent, and Ottawa counties shown on cross section *GG'* do not demonstrate a singular marked lithologic change near the center of the formation. Generally, the coarser sandstones are in the upper half of the formation but the western wells shown in section *GG'* (Fig. 10) are exceptions. A well in north-central Barry County (well 5, Fig. 10) penetrated 275 feet of Marshall sandstone of which all but 40 feet in the center of the formation is fine-grained. If a few feet of the upper part of this sandstone should appear in outcrop, it would probably be noted as lower Marshall strata.

It is concluded from a study of the surface and subsurface character of the Marshall formation in southern Michigan that a division of the Marshall into upper and lower members is not advisable when the division must be based on lithology alone. A division of outcrops based on the presence or absence of fossils may be possible in localities where the medium-grained sands are restricted to the upper part of the formation and the fine-grained sands are restricted to the lower part. Even under these conditions the value of a division of the formation is questionable, because the division could not be extended laterally more than a few miles owing to the lack of outcrops and to the lateral changes of lithology.

SUBSURFACE IN WESTERN AND CENTRAL MICHIGAN

Occurrence of red sediments.—The Marshall formation exhibits several marked lithologic changes basinward from the outcrop area. Although red sediments are absent in the outcrops and appear only in the most western well of section *GG'* (Fig. 10), they are common in the Marshall near the center of the Michigan basin, especially in the lower beds of the formation.

The areal distribution of redbeds in the Marshall formation, where the formation is clearly defined, is shown in Figure 11. Their extent is nearly as great as that of the Marshall itself. They are entirely absent in a relatively narrow area adjacent to the drift-covered outcrop in southern and eastern Michigan. The southern boundary of Marshall redbeds conforms in general with the strike of the strata in southern Michigan.

The eastern limit of red sediments in the Marshall formation shown on Figure 12 may be questioned. In Tuscola, Bay, Arenac, and Ogemaw counties there are



FIGURE 11
AREAS OF MARSHALL RED SEDIMENTS

15 0 15 30
MILES

FIG. 11.—Areas of Marshall red sediments.

redbeds east of the area outlined. In the description of the Coldwater formation the redbeds in these counties are indicated as Coldwater-lower Marshall. East of the area of red Marshall shown in Figure 11, the occurrence of these red zones is limited to strata more than 200 feet below the top of the Marshall. There are no red sediments in the first 100 feet or more of deposits directly underlying the medium- to coarse-grained sandstones in the upper part of the Marshall formation in this area. The eastern limit of Marshall redbeds shown in Figure 11 is therefore the extent of redbeds in the Marshall formation where this formation can be separated from the Coldwater formation in well samples. In those areas where the two formations can not be separated, it indicates the eastern limit of red sediments occurs less than 200 feet below the top of the Marshall formation. Well 17 in cross section *BB'* (Fig. 6) is not included in the area of Marshall red sediments, because the only rebed in this well lies 470 feet below the top of the Marshall.

The relationship of the red color in the Marshall formation to lower Marshall beds and its value as a stratigraphic marker has evoked much discussion. In some small areas the top of the redbeds has been identified as the top of lower Marshall. It was so considered by Eddy (1936, p. 4) in his study of the Crystal oil field in Montcalm County. Kirkham (1932, p. 137) recommended the use of the "Lower Marshall or 'red rock' horizon" as a trustworthy datum for subsurface contour mapping. Prior to the publication of these reports, Newcombe (1929, p. 207) stated that the redbeds were not adaptable for use as a key horizon in the Saginaw oil field.

Enough data are now available to show that a red color in the Marshall deposits is of little value as a stratigraphic marker from a regional point of view, and that the red color is not limited to lower Marshall strata. Cross section *BB'* (Fig. 6) shows the stratigraphic range of red sediments from Oceana County eastward to Genesee County. Although red sediments are more characteristic of the lower beds, they commonly occur in the highest part of the formation in western Michigan. Their thickness and continuity are very irregular (wells 1, 2, 3, and 4, section *BB'*, Fig. 6). The base of the red sediments does not everywhere coincide with the base of the Marshall formation. Any of the included cross sections shows one or more wells in which the color does not extend to the base of the sandstone. As red sediments do not occur in any constant stratigraphic position, it is not practical to attempt a regional separation of the lower Marshall sandstone from the Napoleon (upper Marshall) sandstone on a color basis.

Landes (1944, p. 187) suggested that the division of the Marshall should be based on grain size rather than color in the Porter oil field of Midland County. There is an area in central Michigan from Roscommon County to Clinton County where a division of the Marshall can be made on both color and grain size. This area includes parts of Roscommon, Clare, Gladwin, Isabella, Midland, Gratiot, and Clinton counties. There is a definite lithologic change within the formation, consisting of a noticeable reduction in grain size in the lower part of the section

commonly accompanied by the abrupt occurrence of red color in these finer clastics. Within the area of an oil-producing structure this lithologic change affords an acceptable mapping horizon. The wells in Gladwin County represented on cross section *FF'* (Fig. 5) are in an area in which the Marshall formation can be divided into two well defined members.

Extension of this division toward the west is very difficult. The red color is not limited to the lower part of the Marshall formation and the change in sand grain size does not occur at the same stratigraphic level in many places in western Clare, Isabella, Gratiot, and Clinton counties. The Marshall formation is lithologically similar in the other western counties of the state. In some parts of most of these counties the fine-grained sandstones are restricted to the lower part of the formation and the top of these fine-grained sandstones may be used locally as a stratigraphic marker. However, attempts to determine this marker over the area of even one county are generally unsuccessful. In Newaygo County, in Sec. 35, T. 11 N., R. 13 W., a well penetrated 185 feet of Marshall sandstone of which the top 45 feet is tan sandstone and the remaining 140 feet is red sandstone. The sandstone is fine-grained throughout the section. A well in Oceana County, in Sec. 23, T. 15 N., R. 15 W., penetrated 200 feet of Marshall sandstone. The upper 150 feet is interbedded red and tan, fine- to medium-grained sandstone and the lower 50 feet consists of light gray, fine- to coarse-grained sandstone. These wells show the lithologic variation of the Marshall formation in the western part of the state. It is difficult to establish a typical Marshall section in western Michigan. Cross section *BB'* (Fig. 6) illustrates the variations in color and thickness of the Marshall sediments from west to east.

Relation to Michigan "Stray" sandstone.—Another prominent feature of the Marshall formation northward from the outcrop area in southern Michigan is its irregularity of thickness. Closely associated with the irregularity of thickness is the indefinite nature of the top of the formation. The thickness of the Marshall in the area from Jackson County to Ottawa County represented in cross section *GG'* (Fig. 10) is fairly constant and averages about 275 feet. A thinning of approximately 100 feet occurs 20–30 miles northeast of almost any well shown in this cross section. This change in thickness is illustrated in the southernmost wells of cross section *AA'* (Fig. 4). The Marshall formation in Jackson County is 300 feet thick, whereas 190–230 feet are recorded in Ingham and Shiawassee counties on the north. These figures of thickness represent the interval from the top of the Coldwater formation to the base of the lowest dolomite or shale of the Michigan formation. The sandstone above the lowest dolomite and shale of the Michigan formation in wells 22–25 of cross section *AA'* (Fig. 4) is generally considered to be a "stray" sandstone of the Michigan formation. The stratigraphic relationship of these beds to the sandstones of the Marshall formation is one of the primary stratigraphic problems of the Marshall formation. It is necessary to determine this relationship before generalized statements regarding the thickness and occurrence of the Marshall formation in the western half of Michigan can be made.

Published opinions on the Michigan "Stray"-Marshall sandstone relationship can be classified into two general groups. The first group considers the "stray" sandstones to be reworked and redeposited Marshall sediments. Bergquist (1938, p. 50) points out that this conception of the stratigraphy implies an interruption in sedimentation at the close of Marshall time. Lane and Seaman (1909, p. 81) first suggested an unconformity at the top of the Marshall sandstone. Many years later, Thomas (1931, p. 490) and Kirkham (1932, p. 137) described an unconformity between the Marshall and Michigan formations. Newcombe (1933, p. 81) enlarged upon this concept and suggested that the Michigan "Stray" sandstones were deposited as bars in the Michigan sea following erosion of the top of the Marshall formation. Stearns (1933, p. 101), Eddy (1936, p. 4), and Ball *et al.* (1941, p. 241) have expressed similar opinions.

The second group of views on the Michigan "Stray"-Marshall sandstone suggests a gradational contact between the two formations with sandstones, shales, and dolomites interfingering in an irregular arrangement. Although Cook (1914, p. 64) implied that the contact between the two formations was gradational, he did not discuss the subject. Hard (1938, p. 169) introduced the concept that basal Michigan deposits interfingered with upper Marshall sandstones after he had made a comprehensive study of Michigan gas sands. He described the gas-bearing "Stray" sandstone of the Clare, Vernon and Leaton fields as grading laterally into the Napoleon sandstone, thus making the Napoleon sandstone stratigraphically higher in one area than another. Apparently at the same time, Hake (1938, p. 404) came to the same conclusion, stating that the Michigan "Stray" sands are fingers from the top of the Marshall or isolated lentils contemporaneous with parts of upper Marshall. According to Addison (1940, p. 1967), Michigan sediments were being deposited in one part of Isabella County before Napoleon sandstone deposition had ended in another part of the county 35 miles away.

Sufficient data are now available to justify the general acceptance of the views expressed by Hard and Hake on the gradational relationship of the Marshall and Michigan formations. Although there is an interfingering of the Marshall sandstones with the shales and dolomites in the west-east cross section *BB'* (Fig. 6) and the north-south cross section *AA'* (Fig. 4), this feature is best illustrated in cross section *BD* (Fig. 5) extending northeast from Oceana County into Crawford County. The end wells (1, 2, 8 and 9) in this cross section contain 120-150 feet of Marshall, whereas wells 3 and 4 have 235 and 295 feet, respectively. The cause of this great difference in thickness is a lensing of the upper sandstones, which is shown in the wells in the central part of the cross section. The interfingering of the upper part of the sandstone in the northeast corner of Lake County (well 4) with the dolomite and gypsum deposits of the Michigan formation in Wexford and Missaukee counties (wells 5, 6, and 7) illustrates the stratigraphic relationship of the Michigan "Stray" to the Marshall sandstone. Correlation of the sandstone beds overlying 60 foot of dolomite, shale,

and gypsum in Missaukee County with the thick Marshall section in Lake County is evident.

A similar relationship at the top of the Marshall formation is found in most of the western half of Michigan. As the change from Marshall sandstone deposition to Michigan dolomite, shale, and gypsum deposition was gradual, some of the thinner sandstones included in the Michigan formation may be isolated lentils deposited in the Michigan sea independent of any connection with the Marshall formation. Some of the higher and more discontinuous sandstones shown in the cross sections are probably of this character. It is extremely difficult to separate the sandstone beds completely surrounded by Michigan deposits from the thin fingers of sandstone continuous with the Marshall sandstones unless samples from closely spaced wells are available. Stearns and Cook (1932) attempted to differentiate the sandstones in the Michigan formation from those of the Marshall by differences in mineral composition, but were unsuccessful. The general area in which the Michigan "Stray" sands are mostly fingers from the top of the Marshall is west of central Roscommon County, western Gladwin and Midland counties, western Saginaw, Shiawassee, and Livingston counties.

Thickness.—The thickness of the Marshall sandstone varies appreciably in different parts of the state. The greatest thickness occurs in a well in west-central Ionia County in Sec. 16, T. 6 N., R. 8 W., where 305 feet of light gray to buff sandstone was penetrated. The upper 210 feet of this interval consists of fine- to medium-grained, buff sandstone and the lower 95 feet is a very fine-grained, gray to buff sandstone. Where the top and base of the formation are easily identified, the thinnest Marshall section is in a well in Newaygo County (well 3, cross section *BB'*, Fig. 6). The formation is only 130 feet thick at this locality. The upper 70 feet of the formation in this well consists of small- to medium-grained, buff sandstone which is underlain by 40 feet of fine- to medium-grained, light red sandstone. The basal 20 feet is composed of an upper 10 feet of fine-grained red sandstone and a lower 10 feet of fine-grained tan sandstone.

The thickness of the Marshall formation elsewhere in the western half of Michigan ranges from 130 to 305 feet. It is difficult to determine an average thickness for the formation, because the Marshall deposits interfinger with those of the Michigan. Basinward from the thick sections in southwestern Michigan, the sandstone ranges from 230 to 270 feet in thickness in an area extending northward from central Gratiot County, through eastern Isabella and western Mecosta counties, and thence into Osceola County. The places in which the fingers of Marshall sandstone into the Michigan deposits are best developed are adjacent to the area outlined. The Michigan "Stray" sandstone is thickest and occurs at most places in the area adjacent to the thickest section of Marshall sandstone. This feature is illustrated in cross sections *BD* (Fig. 5), *AA'* (Fig. 4) and *BB'* (Fig. 6). In areas containing the Michigan "Stray" sandstone, there is generally 150–180 feet of Marshall sandstone between the Coldwater shale and the lowest dolomite and shale of the Michigan formation. Overlying this interval of sand-

stone is the zone of interfingering Marshall and Michigan deposits which gives rise to the Michigan "Stray" sandstone. The thickness of the shale and dolomite separating the Michigan "Stray" sandstone from the main body of Marshall sandstone can be as much as 50 feet. The overlying Michigan "Stray" sandstone reaches a maximum of 70 feet in thickness. The total thickness of the sandstones, shales, and dolomites from the base of the Marshall to the top of the Michigan "Stray" rarely exceeds 300 feet. At most places it is about the same as the thickness of the Marshall sandstone in southwestern Michigan where no "Stray" sandstone is evident.

East of the interfingering Marshall and Michigan deposits, and west of the area in which the Coldwater-Marshall contact becomes indistinct, the thickness of the Marshall formation is remarkably uniform. The nine wells at the north end of cross section *AA'* (Fig. 4) illustrate the occurrence of the Marshall a few miles east of the eastern extent of well developed Michigan "Stray" sandstones. The thickness of the Marshall illustrated this cross section is 200 feet in Gladwin County. The formation thins gradually northward to 130 feet in Crawford County. The relationship of the thin Marshall formation in Crawford County to the thicker sandstones on the west is shown in cross section *BD* (Fig. 5). South of Gladwin County, in those restricted areas where the top of the Marshall is a definite stratigraphic horizon as it appears to be in eastern Michigan, and where the Marshall-Coldwater contact is easily recognized, the thickness of the Marshall formation averages approximately 200 feet.

In the southern part of the state, the Marshall formation thickens toward the south. This thickening is shown in the southernmost wells on cross section *AA'* (Fig. 4). An average thickness of 275 feet from Ottawa County to Jackson County is shown on cross section *GG'* (Fig. 10). The Marshall thickness in this area is equal to, and is generally greater than, that of any other locality in the state where the base of the formation can be clearly defined. This is important, as a general thinning of the Marshall formation southwest was described by Lane and Seaman (1909, p. 81) and has been referred to by other authors (Newcombe, 1933, p. 57; Ball *et al.* 1941, p. 241). These geologists compared the thickness of the Marshall formation in southwestern Michigan with the 500 feet of sandstone, shale, and interbedded red sediments in east-central Michigan, which in this report have been shown to be partly Coldwater in age. The reported 560 feet of Marshall sediments in northern Huron County (Lane, 1900, Pl. 1) also has led writers to the erroneous conclusion that the Marshall thins appreciably toward the southwest. It is shown in the discussion of the Coldwater-Marshall strata in northern Huron County that Lane overestimated the thickness of the Marshall formation in that area.

The only area of considerable extent west of central Michigan in which the Marshall formation is less than 200 feet in thickness extends from the drift-covered outcrop in Oceana County, eastward through central Newaygo County and into the western edge of Mecosta County. The thickness of the Marshall

formation ranges from 130 to 160 feet in the center of the area (wells 1, 2, and 3, cross section *BB'* Fig. 6). As shown by the cross section, there is very little sandstone above the lowest gypsum and shale of the Michigan formation. However, toward the margin of the area in northern and southern Newaygo County, fingers of "Stray" sandstone are present extending from the thicker Marshall sections surrounding the area of thin Marshall. North, east, and south of the area of thin Marshall, sandstone deposits thicken in a very short distance. The increase in thickness of the sandstone from Oceana County northward into Lake County is illustrated in cross section *BD* (Fig. 5). The thickening toward the south from Oceana County is equally as great. In the southwest corner of Newaygo County, 240 feet of sandstone is present, which is similar to that in Ottawa County shown in the western part of cross section *GG'* (Fig. 10).

Several important features of the Marshall formation are brought out in the foregoing discussion. There is a definite thinning of the Marshall from northern Midland County northward through Gladwin and Roscommon counties and into Crawford County. The Marshall increases in thickness from Clinton County southward into Jackson, Calhoun, and other counties in southwestern Michigan. The regional thickening from the north-central part to the southern part of the state amounts to 160 feet. A regional southward thickening of the Marshall is not evident in the western part of Michigan. In the area of interfingering Marshall and Michigan sediments in western Missaukee, Wexford, and Lake counties, the thickness of the sandstones with some interbedded shale is almost equal to that found in counties on the south. In Jackson, Calhoun, Barry, Eaton, and southern Ionia counties, the thick sections of Marshall sandstone are uninterrupted by dolomite and gypsum deposits and in only a few places by a thin gray shale. Elsewhere in central and western Michigan, excepting in an area in central Gratiot County, Isabella County, and eastern Mecosta County, the thick sandstone sections are generally interrupted by fingers of Michigan deposits. The area of the thick Marshall sandstone in southwest Michigan is much greater than elsewhere in the state. Thicknesses of more than 250 feet are present in the area from Jackson County in southern Michigan into Muskegon County on the western side of the state.

UPPER MARSHALL OF EASTERN MICHIGAN

The Marshall formation of the eastern half of the Southern Peninsula differs from that in the western part of the state in several ways. The absence of any uniform criteria for separating the Marshall from the Coldwater in the area is mentioned in the discussion of the Coldwater. There is, however, a marked lithologic change in the upper part of the Marshall formation in eastern Michigan. The upper 90-160 feet of sandstone is appreciably more coarse-grained and more poorly cemented than the lower beds. The sandstone is nowhere red, but may be tan, light gray, or white. Both the stratigraphic position and the litho-

logic character indicate that the sandstone corresponds with the Napoleon sandstone member of the Marshall formation.

The stratigraphic relationship and lithologic character of the Napoleon sandstone from western Gladwin County in the central part of the Michigan basin to the eastern margin of Arenac County are illustrated in cross section *FF'* (Fig. 5). The wells in Gladwin County on this cross section (wells 1, 2, and 3) are in an area in which the Marshall formation can be separated from the Coldwater formation and in which it can be divided into upper and lower members on a lithologic basis. Although east of Gladwin County a persistent lithologic basis for separating the Marshall from the Coldwater is absent, the Napoleon sandstone can be separated from the lower sediments. This medium-grained, loosely cemented sandstone ranges from 110 to 150 feet in thickness in the wells shown in cross section *FF'*. Coarse sand grains are commonly mixed with grains of smaller size near the base of this member.

Similar occurrences of Napoleon sandstone are found in most of the eastern Michigan counties. The sandstone has an average thickness of 120 feet and can be recognized eastward from Gladwin, Midland, and Saginaw counties to the drift-covered outcrop area.

The areal extent of the Napoleon sandstone westward as a separate lithologic unit is variable. It has been mentioned that the Marshall is divisible into members in parts of Clare, Isabella, Gratiot, Midland, and Clinton counties. The value of the Napoleon as a mappable unit is less in these counties due to its interfingering relationship with the Michigan formation.

No evidence was observed in the well samples from the eastern part of the state which indicates that the sandstones above the lowest dolomite, limestone, and shale of the Michigan formation are lateral extensions of Marshall sandstone. The Michigan sandstones in this area are commonly finer-grained and better cemented than the Napoleon sandstone. They are interbedded with shale, dolomite, and gypsum and are less than 20 feet thick at most places. The top of the Marshall in eastern Michigan, therefore, is an acceptable stratigraphic marker and generally can be used as a datum for structure mapping.

COLDWATER-MARSHALL STRATA IN NORTHERN HURON COUNTY

INTRODUCTION

The stratigraphy in northern Huron County is discussed separately because the lithologic character of the Marshall and upper Coldwater beds in this area is somewhat different from that elsewhere in the state. The two main problems are the correlation of the outcrops along the shore of Lake Huron and the location of the Coldwater-Marshall contact. A brief description of the outcrops is first given, followed by a correlation of the outcrops based on subsurface information. The regional dip is southwest in Huron County and the outcrops are described from west to east, or in general from the top of the Marshall formation to the

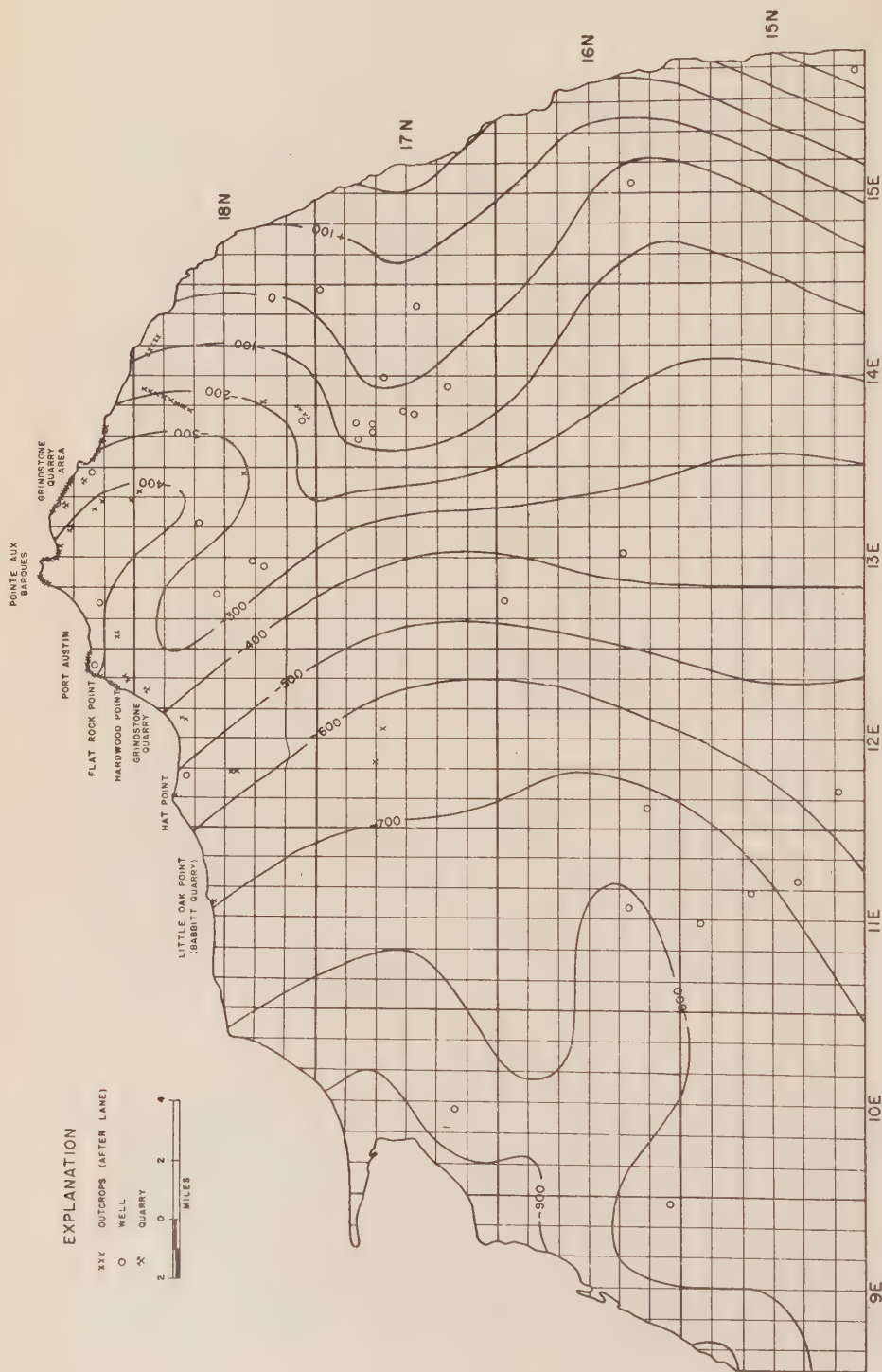


FIGURE 12 HURON COUNTY
SUBSURFACE STRUCTURE CONTOUR MAP ON THE
BASE OF THE COLDWATER
CONTOUR INTERVAL = 100 FEET

base. The outcrops are discussed in this sequence in order to start with known Marshall rocks and proceed to beds which are of questionable Marshall age.

OUTCROPS

The uppermost beds of undoubted Marshall sandstone crop out on the north and south sides of Rush Lake, inland from Little Oak Point (Fig. 12). The best exposure is in an abandoned quarry between an old east-west road and the present road in Sec. 15, T. 18 N., R. 11 E. Although the lower 5 feet of strata is covered with water, about 14 feet of medium- to coarse-grained, very friable sandstone, speckled throughout with limonite, is exposed in the quarry. With the exception of the top 3 feet of thin-bedded strata, the beds are massive and cross-bedded. Lane (1900, Pl. 1) assigned the strata at Babbitt quarry to the middle part of the Napoleon sandstone.

East of the Rush Lake exposures, the first outcrop of the sandstone along the shore line is at Hat Point in Sec. 7, T. 18 N., R. 12 E. Twelve feet of fine- to coarse-grained, cross-bedded sandstone is exposed. Streaks of small quartz pebbles and flakes of black carbonaceous material occur in the rock. The color ranges from buff to greenish gray. Lane (1900, p. 19) assigned this sandstone to the base of the Napoleon.

Two miles inland from Hat Point, about 10 feet of sandstone is exposed along Taft Drain in the NE. $\frac{1}{4}$ of Sec. 20, T. 18 N., R. 12 E. The rocks exposed range from very fine-grained, green sandstone to coarse-grained, tan sandstone. The different lithologic types grade into one another vertically and laterally. A small exposure of fine- to medium-grained, greenish tan, non-fossiliferous sandstone is found in the bed of the small creek near the center of Sec. 5, T. 17 N., R. 12 E.

East of Hat Point is an outcrop which was not available to the early geologists. The exposure is the result of grindstone quarry operations which began at this locality after Lane (1900) had completed his field work in Huron County. The quarry is southwest of Hardwood Point on both sides of the present highway in Sec. 2, T. 18 N., R. 12 E., and exposes about 9 feet of strata. The upper 7 feet is thin-bedded, grayish green, very fine-grained sandstone, but the lower 2 feet is more massive. The latter is underlain by a more massive sandstone, as indicated by the thick large slabs lying around the pit. There are small pebble zones an inch or two thick throughout the sandstone, but they disappear laterally over a distance of a few yards. There also are some larger individual pebbles scattered throughout the very fine-grained sandstone which was used for grindstones. Large fragments of brown, pebbly conglomerate which resembles peanut brittle candy are found on the north side of the road. Lane (1900, p. 19) applied the term "peanut conglomerate" to rock of identical appearance occurring near Grindstone City.

A few feet of very thin-bedded, fine-grained, greenish to reddish sandstone are exposed at Hardwood Point, one mile northeast of the grindstone quarry previously mentioned. The rock is lithologically very similar to the sandstone from which grindstones were cut. Winchell (1861, p. 80) noted that the sandstone

at Hardwood Point contained fossils which are characteristic of the "Marshall group." The strata at this locality appear to have a northeast dip.

The shore of Lake Huron is barren of rock ledges from Hardwood Point to Flat Rock Point (Fig. 12). A medium- to coarse-grained, light gray sandstone crops out along the shore from Flat Rock Point to Port Austin. The sandstone is massive and cross-bedded and is ordinarily soft. There are many seams of small pebbles throughout this sandstone which disappear laterally. There are approximately 25 feet of sandstone exposed. At Broken Rocks, $\frac{1}{2}$ mile west of Port Austin, the sandstone has been broken into huge blocks by joints which give the shoreline a very distinctive appearance. East of Broken Rocks the massive sandstone is succeeded by thin-bedded, greenish to reddish, fine-grained sandstone rising only a foot or two above the water. The fine-grained sandstone is the easternmost outcrop west of Port Austin. There is a great similarity between this sandstone and that at Hardwood Point. The sandstone is capped by a band of "peanut conglomerate" 8 inches thick.

Inland from Flat Rock Point, in the NE. $\frac{1}{4}$, NW. $\frac{1}{4}$ of Sec. 36, T. 19 N., R. 11 E., recent removal of 2 feet of top soil over an area of approximately 300 square feet has exposed fine-grained, tan to reddish tan, very thin-bedded sandstone in which a few fossils were found.

South of Port Austin, a hill rises above the surrounding country to the highest elevation in this part of Huron County. Although no bedrock was seen, slabs of sandstone are abundant over the entire hill. At the top of the hill the slabs consist of medium- to coarse-grained, grayish white to tan sandstone. Fragments of a fine-grained, green to tan sandstone are on the flanks of the hill.

The sandstone cliffs at Pointe aux Barques are the first outcrops east of Port Austin. These cliffs rise 19 feet above Lake Huron and are composed of sandstone very similar to that found west of Port Austin. It is massive, cross-bedded sandstone with grain sizes ranging from fine to coarse. The sandstone is light gray to buff, friable and porous. It occupies about $\frac{3}{4}$ mile of the shoreline in the vicinity of Pointe aux Barques. These beds appear to have a slight dip southwest which Winchell measured as $1\frac{1}{2}^{\circ}$.

Eastward from Pointe aux Barques no bedrock is exposed along the lake shore to the vicinity of Eagle Bay. Near the center of Sec. 23, T. 19 N., R. 13 E., the "grindstone" beds come to the surface. Lane (1900, p. 21) describes the interval from the base of the sandstone at Pointe aux Barques down to the grindstone beds as being composed of beds which "become gradually thinner and finer grained . . . until finally we have a little blue shale, and . . . narrow seams of calcareous sandstone covered with *Camarotoechia* (*Rhynconella*) *camerifera* and *Romingerina* (*Centronella*) *julia*." The fossil zone referred to by Lane is found on the north side of the east-west road, extending through the center of the E. $\frac{1}{2}$ of Sec. 26, T. 19 N., R. 13 E. The rock containing these fossils is 3 feet of calcareous, well cemented, very fine-grained, gray to brown sandstone cropping out about 200 feet east of the intersection of this road and a north-south road extending through the center of the section.

East of Burnt Cabin Point in Sec. 23, T. 19 N., R. 13 E., the fine-grained, greenish sandstone which was quarried so extensively for grindstone purposes prior to 1900 crops out along the shore intermittently more than 2 miles. Lane (1900, p. 22) estimated this sandstone to be 25 feet thick. These beds occupy the shoreline more or less continuously until they grade downward into blue-gray shale in the shore cliffs in Sec. 30, T. 19 N., R. 14 E. (Fig. 13). It is at the top of this shale that Lane (1900, p. 22) placed the Coldwater-Marshall contact.

Immediately overlying the grindstone beds, according to Lane (1900, p. 21),



FIG. 13.—Interbedded sandstone and shale underlying "Grindstone" beds along shore of Lake Huron, Huron County, Michigan.

is a "peanut conglomerate." This conglomerate was not found in place either at the quarries or on the lake shore, but fragments are numerous and its position as described by Lane is not questioned.

The sandstone which was used as grindstone is a very fine-grained, greenish sandstone occurring in beds one inch to a foot in thickness. Large rounded quartz pebbles which caused the grindstone makers considerable trouble are scattered throughout most of the sandstone. The sandstone is moderately hard and the crushed samples show it to be somewhat argillaceous. All of the deeper quarries are now filled with water, but an examination of discarded quarried blocks from the sandstone suggests that there are no lithologic differences between the top and the bottom of the grindstone beds.

The only remaining exposures in Huron County which have been described

by other workers in connection with the outcrops described are those found along Willow River in T. 18 N., R. 14 E. The outcrops are more or less continuous from Huron City upstream through Sections 4 and 9, where alternating beds of sandstone and shale are exposed, with the sandstone predominating. Twenty-five feet upstream from the highway bridge at Huron City and 10 feet above the creek bottom is a very fossiliferous, fine-grained shaly tan sandstone.

Sand grain size and color has been emphasized in the discussion of the sandstones cropping out in northern Huron County. Excepting for these two features, there is little lithologic difference in the various sandstones. Neither the coarse nor the fine sand grains have frosted surfaces. The roundness of the grains varies slightly with the size, the coarser grains being more rounded than the finer. Most of the binding material is both argillaceous and ferruginous, although some zones in the sandstones are calcareous.

Thin sections were made of samples of sandstone collected at Hat Point, Pointe aux Barques, and at a grindstone quarry near Grindstone City. The mineral composition in these thin sections is almost identical. Quartz, chert and fragments of mica schist are the main components of the sandstones. Approximately 95 per cent of the rock fragments in each slide is composed of quartz and chert. Tourmaline and zircon occur in small amounts. A low feldspar content is characteristic of the rocks. A few fragments of orthoclase and plagioclase feldspar are present in the sandstone, but their abundance does not surpass that of biotite, chlorite, sericite, apatite, or ilmenite.

CORRELATION OF OUTCROPS

The correlation of the outcrops described has been a subject of contention since the publication of Winchell's original description (1861, pp. 80-83) of the strata cropping out along the north shore of the county. Rominger (1876, p. 75) objected to Winchell's idea that stratigraphically the sandstones were successively lower from west to east along the shore. He believed that most of the sandstones were at about the same stratigraphic level.

The most detailed geologic study in Huron County was made by Lane (1900). After a thorough investigation of the data from water wells and an examination of practically all of the outcrops in Huron County, Lane expressed the opinion that Winchell's original interpretation of the relationship of the sandstone beds cropping out along the shore of Lake Huron was correct. He (Lane, 1900, Pl. 1) compiled a detailed stratigraphic column showing 560 feet of Marshall strata, of which 300 feet is classified as Napoleon.

Because of the absence of a stratigraphic marker in the Marshall and Coldwater sediments which could be used as a horizon for mapping the structure of this area, Lane was greatly handicapped in securing accurate data on the amount of folding of these beds. Although subsurface data are still not plentiful in Huron County, a sufficient number of wells have now been drilled through the base of the Coldwater to permit a much better understanding of the succession of beds

in the Marshall and Coldwater formations. A solution to the northern Huron County stratigraphic problem based on subsurface data almost entirely is presented in the following paragraphs. It differs from both the Winchell-Lane interpretation and the Rominger concept, but it is a compromise of the two.

The problem is primarily one of structure, as correlation of the individual beds is much less difficult when the structure is understood. The structural contours shown in Figure 12 are on the base of the Coldwater formation, which rests on the Sunbury black shale in Huron County. The largest structural anomaly in this area is the anticlinal fold and associated syncline in the northernmost part of the county. The elevation of the base of the Coldwater on the crest of the anticline is more than 125 feet above the elevations on the northeast and southwest. The northwest extension of the fold into Saginaw Bay is indicated by the increasing influence of the fold on the structure contours from southeast to northwest. It appears certain that the fold must involve some of the shoreline outcrops. The syncline on the northeast can not be outlined as accurately as the anticline due to insufficient data. Its presence is unquestioned, however, as the dip on the northeast flank of the anticline must revert to the southwest regional dip in this area. Lane (1900, p. 92) recognized a northeast dip between Hardwood Point and Flat Rock Point, but he minimized the importance of the dip. Structural control points in the synclinal area are obtained from very incomplete data of old Berea brine wells. In a well very close to Flat Rock Point in Sec. 25, T. 19 N., R. 12 E., and in a second well approximately 2 miles east in Sec. 29, T. 19 N., R. 13 E., the Berea sandstone was penetrated at depths greater than 500 feet below sea-level. As the average thickness of the Sunbury, which separates the Berea from the Coldwater, is approximately 100 feet, the base of the Coldwater is between 400 and 460 feet below sea-level. Another abandoned Berea brine well near Grindstone City, in Sec. 25, T. 19 N., R. 13 E., apparently is on the northeast flank of the syncline. The base of the Coldwater is approximately 320 feet below sea-level in this well.

The effect of this anticline and syncline on Winchell's and Lane's correlation of the outcrops along the shoreline is obvious. There are four general outcrops of coarse-grained sandstone along the north side of Huron County (Fig. 14): (1) near Little Oak Point in Sec. 15, T. 18 N., R. 11 E., (2) Hat Point in Sec. 7, T. 18 N., R. 12 E., (3) Flat Rock Point to Port Austin, and (4) Pointe aux Barques. The coarse-grained sandstone at Flat Rock Point-Port Austin appears to be correlative with the sandstone of identical character at Pointe aux Barques. This sandstone occurs approximately 1,000 feet above the base of the Coldwater and is 25 feet thick. Shale, sandy shale, and the fine-grained, greenish sandstone from which grindstones were cut underlie this coarse-grained sandstone. The grindstone beds in the vicinity of Grindstone City are the same strata which were quarried southwest of Port Austin in Sec. 2, T. 18 N., R. 12 E. Lane's (1900, Pl. 1) measured interval of 40 feet between the base of the Pointe aux Barques sandstone and the top of the grindstones is not questioned. The fine-

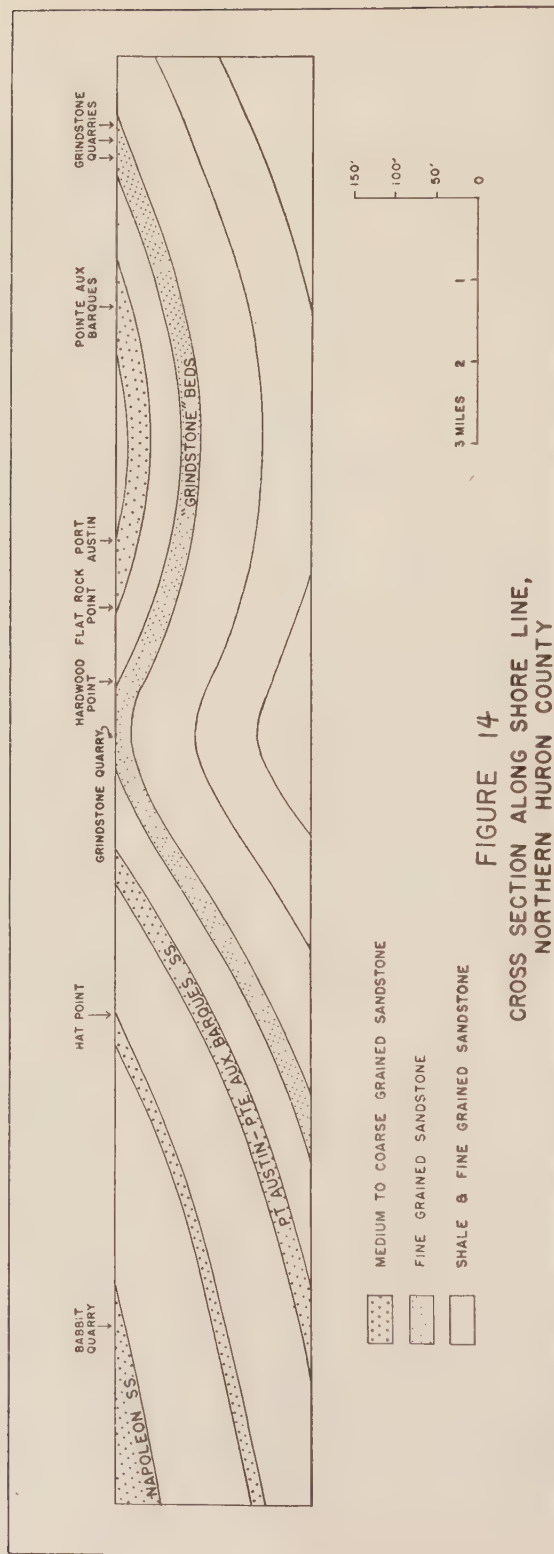


FIGURE 14
CROSS SECTION ALONG SHORE LINE,
NORTHERN HURON COUNTY

Fig. 14.—Cross section along shoreline, northern Huron County, Michigan.

grained sandstone with interbedded shale cropping out at Hardwood Point is characteristic of the zone between the coarse-grained sandstone of Pointe aux Barques and the main grindstone zone.

If these correlations are correct, the 95 feet of sediments in Lane's stratigraphic column (1900, Pl. 1) between the Port Austin coarse-grained sandstone and the Pointe aux Barques coarse-grained sandstone is a repetition of beds due to folding. The question then arises whether the coarse-grained sandstone at Hat Point west of the anticline is correlative with the Flat Rock-Port Austin-Pointe aux Barques sandstone as Rominger (1876, p. 74) suggested. Data obtained from a well recently drilled within a mile of Hat Point show the improbability of this correlation. The base of the Coldwater lies 520 feet below sea-level in this well, or approximately 100 feet lower than at Port Austin and Pointe aux Barques. The surface elevation along the north shore of the county where the outcrops under discussion occur is approximately 600 feet (water level = $581 \pm$ feet). The sandstone at Hat Point is therefore about 1,100 feet above the base of the Coldwater, whereas the Port Austin-Pointe aux Barques sandstone is 1,000 feet above this datum. It appears that Lane was correct in separating the Hat Point sandstone from the Port Austin sandstone. His stratigraphic column (Lane, 1900, Pl. 1) shows an interval of 85 feet between the two.

The most western exposure of these coarse-grained sandstones in northern Huron County is in the abandoned Babbitt quarry near Little Oak Point in Sec. 15, T. 18 N., R. 11 E. There is general agreement that this sandstone belongs to the Napoleon. Although control for structural contours is meager in this area, the base of the Coldwater is estimated to be about 700 feet below sea-level, and as the elevation of this outcrop is approximately 600 feet above sea-level, the sandstone is slightly more than 1,300 feet above the base of the Coldwater.

Lane (1900, p. 19) assigned a thickness of 300 feet to the Napoleon sandstone on the assumption that the drift-covered outcrop extended from Babbitt quarry to Hat Point, a distance of nearly 4 miles. He wrote, however, "the thickness of 300 feet above mentioned is not obtained directly, and may include, as did Winchell, some of the bluish micaceous sandy shales which we have estimated in the overlying group."⁴ It is apparent from the subsurface information now available that the thickness of the Napoleon sandstone rarely exceeds half of this amount. Lane (1900, p. 19) noted a thickness of Napoleon of 135 feet at Bayport in Sec. 5, T. 16 N., R. 10 E., and of 110 feet at Pigeon in Sec. 11, T. 16 N., R. 10 E. Other wells penetrating a complete section of Napoleon in Huron County show an average thickness of 120 feet. Until a well is drilled which proves a great thickening of the upper Marshall sandstone in the area between Babbitt quarry and Hat Point, it appears most logical to accept the available subsurface data on the thickness of the Napoleon sandstone in Huron County.

An interpretation of the stratigraphy along the north shore of Huron County based largely on subsurface data may be summarized as follows. There are three coarse-grained, cross-bedded, poorly assorted sandstones. The lowest is the 25

feet of sandstone cropping out between Flat Rock Point and Port Austin, and at Pointe aux Barques. This sandstone is 1,000 feet above the base of the Coldwater. The second sandstone, lithologically identical, occurs 80-100 feet above the lowest sandstone. There is 15 feet of this sandstone exposed at Hat Point. The third and uppermost coarse-grained sandstone is the Napoleon, which is exposed near Little Oak Point. The thickness of the Napoleon sandstone is assumed to be 120 feet with its base 1,200 feet above the base of the Coldwater. Shale, sandy shale, and fine-grained sandstone separate the three coarse-grained sandstones. The total thickness of the section from Little Oak Point to the base of the grindstone beds at Grindstone City is about 350 feet.

COLDWATER-MARSHALL CONTACT

Correlation of the strata from Little Oak Point to Grindstone City in Huron County with the Marshall formation elsewhere in the state has been accepted since Winchell's original study. It has been demonstrated that it is extremely difficult to separate the Marshall from the Coldwater in the eastern part of the Southern Peninsula on subsurface data. The value of a separation based on the present surface information is questionable. In order to include all of the sandstones from Little Oak Point to Grindstone City in the Marshall formation, it is necessary to assume that the Coldwater is less than 1,000 feet thick in northern Huron County. As previously noted, however, a regional thickening of the Coldwater occurs from the west to the central part of the state and a thickening of the Coldwater-lower Marshall interval toward the east takes place in Arenac and Iosco counties. A thickening of the Coldwater-lower Marshall interval northward from Tuscola County also is indicated by a comparison of wells in Tuscola County with those in western Huron County. Wells 3, 4, and 5 (cross section *CC'* Fig. 7) in Tuscola County show a combined Coldwater-Marshall thickness of 1,225-1,250 feet including approximately 110 feet of Napoleon sandstone. In Huron County this interval is 1,325 feet in wells in Sec. 4, T. 15 N., R. 11 E., and in Sec. 28, T. 17 N., R. 10 E., with the thickness of the Napoleon remaining constant.

The well samples available to the writer are inadequate for accurate tracing of the coarse-grained sandstones of northern Huron County southwest into Tuscola County, where they lens out or become fine-grained. A well in southern Huron County in Sec. 32, T. 15, T. N., R. 12 E. (well 6, cross section *CC'*, Fig. 7) is the northeasternmost well in this area from which samples are available through almost the entire Coldwater-Marshall sequence. The lowest medium- to coarse-grained sandstone in this well is about 950 feet above the base of the Coldwater. It probably is the Pointe aux Barques-Port Austin sandstone, which is estimated to be 1,000 feet above the base of the Coldwater in northern Huron County.

In view of the fact that no reliable means for separating the Coldwater from the lower Marshall deposits have been recognized in this study, it is impossible to state that the thickening of the Coldwater-Lower Marshall strata eastward

into Huron County is limited solely to beds of Marshall age or to beds of Coldwater age. It seems unlikely, however, that the Coldwater in northern Huron County is less than 1,000 feet thick. Thicknesses greater than 1,000 feet occur throughout central Michigan from Kalkaska County to Jackson County and the Coldwater formation should thicken eastward toward the sandy, near-shore facies. It appears advisable to refer to the strata cropping out along the shore of Lake Huron eastward from Hat Point as Coldwater-lower Marshall until further information is available.

MICHIGAN FORMATION

The Michigan formation consists of the beds of shale, limestone, dolomite, gypsum, anhydrite, and sandstone that overlie the Marshall sandstone. Basal Michigan sediments are generally gray shale or gray to brown dolomite, although gypsum and anhydrite beds may be only a few feet above the Marshall sandstone in the western part of the state.

The most distinctive rocks of the formation are the gypsum and anhydrite. They occur throughout the entire Michigan strata in varying stratigraphic positions and amounts. Although in some places well samples representing a vertical distance of 40 feet are composed mostly of gypsum, it is difficult to trace any particular bed laterally for more than a few miles. The gypsum commonly grades laterally into shale and occurs at most places interbedded with shale. Gypsum and anhydrite are most abundant in the lower part of the formation (Newcombe, 1933, p. 57) and are most common in the western part of the state.

A bed of brown crystalline dolomite in the lower part of the formation has been frequently used as a stratigraphic marker in central Michigan (Hard, 1938, p. 136). Hard (1938, p. 137) noted that there is very little sandstone above this dolomite, but below the bed at varying distances is the "Stray" sandstone.

Although not a common feature of the Michigan formation, beds of oölitic limestone were penetrated in a well in Sec. 33, T. 25 N., R. 3 W., in Kalkaska County, and in a second well in Sec. 35, T. 16 N., R. 3 E., Bay County. Elsewhere the limestones of the Michigan formation are gray to buff, very fine-crystalline rocks which are dolomitic at many places.

The thickness of the Michigan formation varies considerably over the state. Newcombe (1933, p. 58) wrote, "The formation may be locally absent but generally it is from 50 to 550 feet thick." Hard (1938, p. 136) reported thicknesses ranging from 250 to 400 feet in the central part of the state. According to Bergquist (1938, p. 49), the formation generally thins toward the margin of the Michigan basin.

AGE AND CORRELATION

Winchell (1870) terminated his publications on the "Marshall group" with an extensive discussion of the age and correlation of the strata. In this report he included an excellent review of publications pertaining to the subject as well as definitely stating his beliefs about Marshall "equivalents" elsewhere in the

United States. After listing 416 species of fossils from the Marshall "and its supposed equivalents," and indicating the states in which they are found, he (Winchell, 1870, pp. 396-97) concluded,

With such an extended network of identifications, and with long lists of representative species which I forbear to cite, I believe it will be admitted that the several formations brought under comparison must have been accumulated in one geological period. Let it now be distinctly stated what are the formations which are thus synchronized. They are as follows:

1. The Marshall Group of Michigan.
2. The Gritstone and Waverly series of Ohio, down to the Chocolate Shales.
3. The Goniatile Limestone of southern Indiana, and its equivalent sandstone in northern Indiana.
4. The Kinderhook Group of Illinois.
5. The Yellow Sandstone series of Iowa, at least down to the bluish sandy shales.
6. The series known in Missouri as the Chouteau Limestone, the Vermicular Sandstone and Shale, and the Lithographic Limestone.
7. The Silico-bituminous Shales at the base of the Silicious Group of Tennessee.

Winchell (1870, p. 415) stated that the age of these strata is the "Upper part of Catskill Group including 'Carboniferous' conglomerate and 'Chemung' conglomerate."

Winchell's correlation of the Marshall with Kinderhook strata has been generally followed by Michigan geologists (Lane, 1895, p. 19; Lane and Seaman, 1909, p. 79; Smith, 1912, p. 29). Perhaps the greatest deviation from Winchell's suggested correlations is shown in a correlation chart by Newcombe (1933, p. 50). The latter places the Coldwater and Marshall strata of Michigan and the upper part of the Waverly of Ohio in the Osage group, whereas the Rockford and Chouteau are shown to be of Kinderhook age. Ballard (1938, p. 1521) repeated this correlation in his Mississippian correlation diagram for central United States.

A copy of the first revision of the Geological Society of America "Mississippian Correlation Chart" (dated April 10, 1945) was made available to the writer by J. M. Weller. Coldwater and lower Marshall strata are shown on this chart in the upper part of the Kinderhook series with the Napoleon sandstone (upper Marshall) in the basal part of the Osage group. The Rockford limestone of Indiana, the Chouteau limestone of Missouri, the lower part of the Cuyahoga formation of the Waverly group of Ohio, and the larger part of the Coldwater shale are shown in approximately the same stratigraphic position in the upper Kinderhook series.

G. M. Ehlers, paleontologist at the University of Michigan, noted a similarity of some goniaticites in the Marshall sandstone to certain species in the Rockford limestone of Indiana. He recently sent some of these Marshall specimens to A. K. Miller at the State University of Iowa for identification, as Miller (1935, pp. 434-35) had previously suggested that the Marshall was correlative with the Rockford and was Kinderhook in age. In a letter dated April 17, 1947, to Ehlers, Miller wrote that "the Marshall sandstone goniaticites are so close to those of the Rockford limestone that the two formations are almost certainly correlative."

As the Rockford limestone is the name since given to the "Goniatile group of

southern Indiana" referred to by Winchell, this confirms the correlation made by Winchell in 1870. There seems little doubt that the Marshall formation is Kinderhook in age and should be correlated, in part at least, with the Rockford limestone and its equivalents in other states.

STRUCTURAL GEOLOGY

The base of the Coldwater formation is the youngest stratigraphic surface in Michigan on which structural contours can be drawn with accuracy over the greater part of the Lower Peninsula. The top of the Coldwater lends itself to this purpose in the west half of the state, but not in the east half, due to the indefinite Marshall-Coldwater contact. The top of the Marshall can be contoured accurately in the east half of the state but not in the west. Lateral lithologic changes cause the beds younger than Marshall to possess no well defined stratigraphic marker that is of value for regional mapping, although a few of these younger beds provide satisfactory markers in some parts of the state.

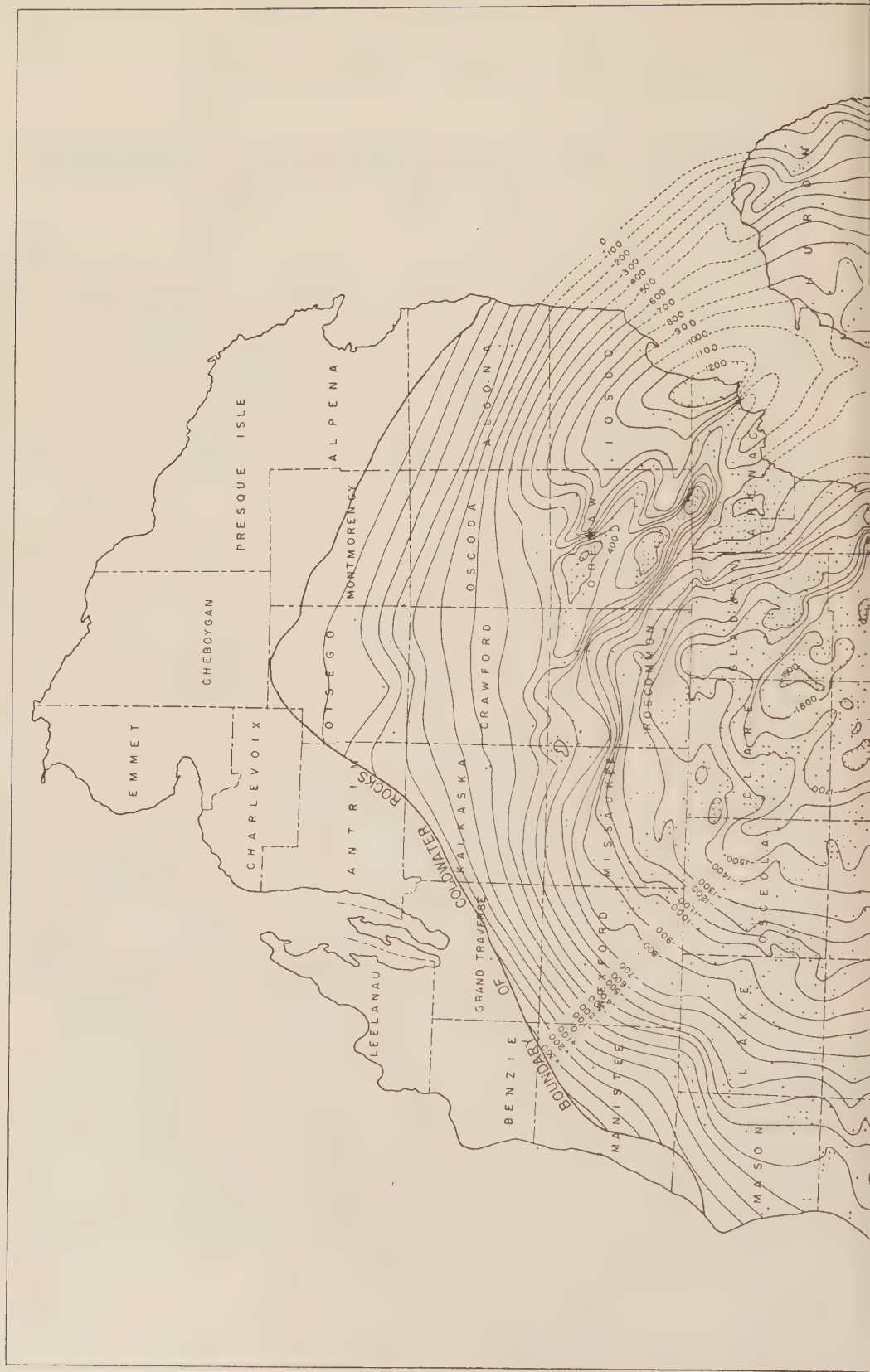
The structure of the rocks in the Southern Peninsula of Michigan at the base of the Coldwater formation is shown in Figure 15. Although the maximum structural relief exhibited on this surface approaches 2,700 feet, this figure does not represent the total relief originally, as older beds continue to rise beyond the limits of the Coldwater formation around the margin of the basin.

Regional dip into the center of the Michigan basin on the base of the Coldwater averages 20-25 feet per mile. Variations in dip both greater and smaller may be measured in almost any part of the state.

As shown in Figure 15, the deepest part of the structural basin lies in the southern Clare-Gladwin County area. Reflection of the structure in older beds by the base of the Coldwater is evident in the comparison of Figure 15 with structure-contour maps based on lower stratigraphic units. Cohee and Underwood (1945) show the deepest part of the basin, as revealed by structure contours on top of the Dundee-Rogers City sequence, to be in the almost identical area. In a study of the Salina and Bass Island rocks in Michigan, Landes (1945) designates this same area as the center of the basin.

The largest anticline contained within the limits of the Michigan basin is the Howell anticline trending northwest through Livingston County in the southeast part of the state. The structure may be described as an asymmetrical anticline plunging northwest with faulting on the steeper southwest side. This faulting has been described by Newcombe (1933). Cohee and Underwood (1945) report the recognition of a fault in a well located on the anticline in the central part of Livingston County. The maximum elevation of the base of the Coldwater on the Howell anticline amounts to 770 feet above sea-level near the center of Livingston County. The minimum elevation of this horizon in the vicinity of the structure may be taken as 1,000 feet below sea-level.

With the exception of the Howell anticline, the larger structural irregularities of the Michigan basin seem to be confined to the northeast part of the Southern



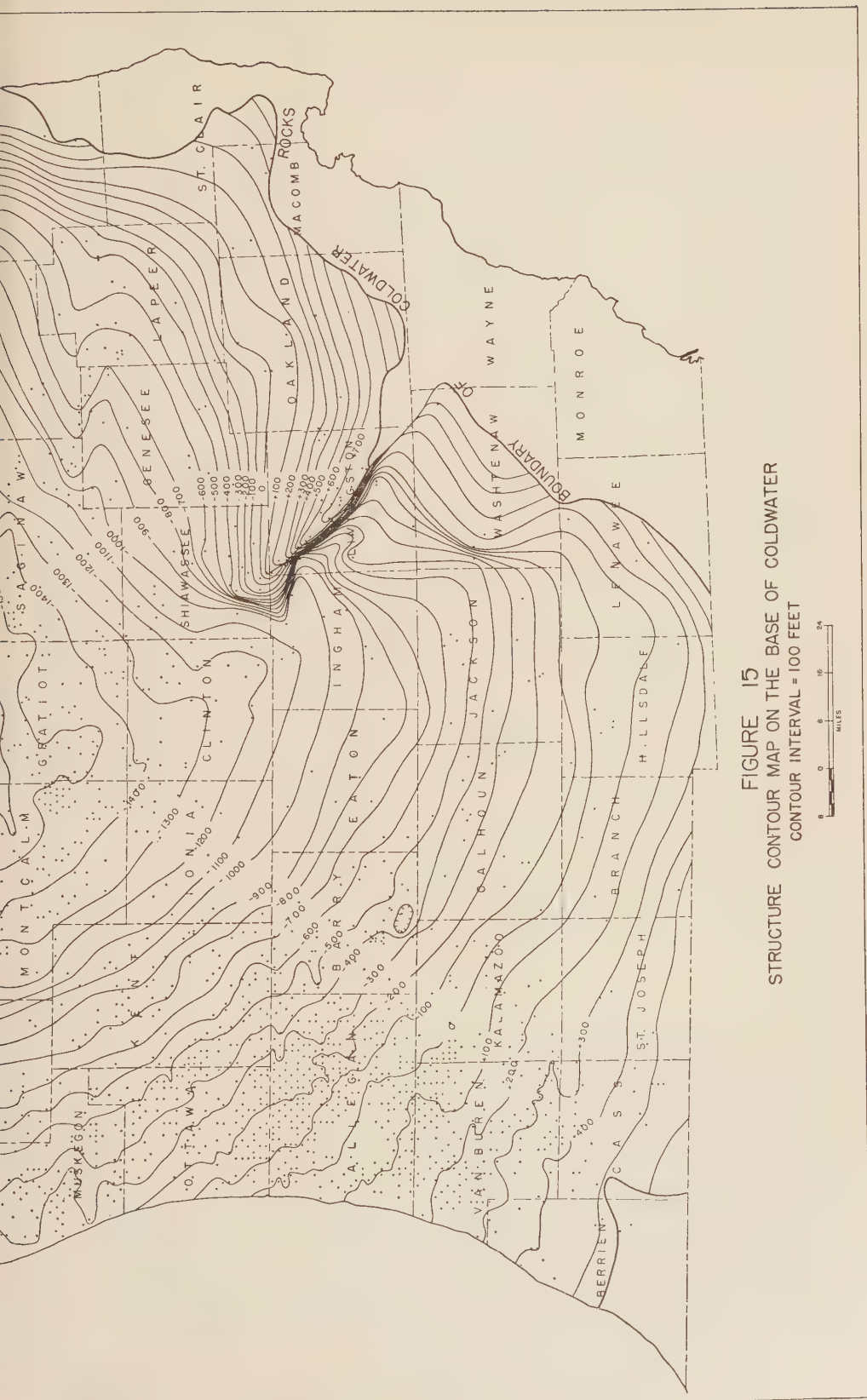


FIGURE 15
STRUCTURE CONTOUR MAP ON THE BASE OF COLDWATER
CONTOUR INTERVAL = 100 FEET

FIG. 15.—Structure-contour map of base of Coldwater formation.

Peninsula, especially in the vicinity of Saginaw Bay. From the east-west trending syncline in Tuscola County north to Oscoda County the beds have been folded appreciably and the general basin character of the rocks is greatly obscured. Three northwest-southeast anticlinal trends are recognized in Ogemaw and Arenac counties in *en échelon* arrangement. Dips as steep as 200 feet per mile are encountered locally. Closure on the higher parts of these folds may be found to reach 175 feet. Other structurally high areas of less definite outline and magnitude are found in Bay and Tuscola counties immediately south of Saginaw Bay.

Saginaw Bay itself presents an area in which speculation as to structure is most interesting, especially to the petroleum geologist. Anticlinal trends from the northwest in Arenac County should extend southeastward into the bay. The beds on the north limb of the Bay-Tuscola syncline continue to rise on the north with no indication of a dip reversal. This reversal and the resulting anticline must occur under the bay. It thus appears possible that the structure of the rocks underlying Saginaw Bay is more complicated than indicated on earlier maps.

The largest, most definite fold trending east and west in the state is the syncline occupying central Tuscola County and southeast Bay County. It is bounded on the north by an anticlinal ridge of approximately the same extent and direction. Closure of the contours on the west end of the syncline appears to be the most logical interpretation of structure on the base of the Coldwater formation, although structure maps on lower formations do not exhibit this closure.

The larger folds in the central part of the basin exhibit a general northwest-southeast trend. Closures approaching 150 feet are shown on the base of the Coldwater in this area. Other anomalies in the structural basin of Michigan are of more indefinite size and trend. They are distributed in an apparently unrelated arrangement throughout western and southwestern Michigan, usually appearing as local variations in direction of the 100-foot contours (Fig. 15). Closure of a contour around the structures, as in the northwest corner of Barry County, depends on the stratigraphic horizon on which the contours are based, as well as the number of control points available.

HISTORICAL GEOLOGY

COMPILATION OF EVIDENCE

A geologic history of Marshall time can be constructed from a consideration of the following pertinent information.

1. *Character of Coldwater depositional basin.*—The Coldwater basin of deposition was an area of marine sedimentation in which mud and carbonate material were being deposited in the deeper and quieter waters covering the western part of Michigan. In the eastern part of the state, mud and coarser clastics accumulated, indicating that the area was much nearer the shore of the Coldwater sea. The relatively uniform lithologic character of the Coldwater sediments from bottom to top in any area indicates that from the beginning to the end of Coldwater time conditions remained fairly uniform excepting in the extreme near-shore area in the east.

2. *Absence of unconformity between Coldwater and Marshall strata.*—It is emphasized in the discussion of the Coldwater formation that the source of the sediments during Coldwater time was at the east and lower Marshall deposition was so similar to that of the upper Coldwater that the accumulation of sediments in the eastern part of the state must have been continuous from Coldwater into Marshall time. Although in the western part of Michigan there is generally a marked change from Coldwater shale to Marshall sandstone, this change in sediments is largely an increase in the grain size of clastics and does not indicate an unconformity.

3. *Lithology of Marshall sediments.*—The sandstones and siltstones of the Marshall apparently were deposited in a shallow sea which frequently was disturbed in its entire area by waves and currents. The Marshall sediments are generally fairly well sorted locally, but lateral gradations in grain size are common throughout the sandstones. Areas near the center of the state, in which gray and red silt accumulated, were probably places in which there was less agitation of the water due to the greater depth.

Red sediments were carried into the Marshall sea during early Marshall time from the land areas on the east and west. It is probable that by the middle of Marshall time, very little red sediment was coming into the depositional area. The fine red silts brought in during early Marshall time were intermittently shifted around over the sea floor in some areas in the west in Michigan throughout later Marshall time.

4. *Present areal distribution of redbeds in Marshall formation.*—It is the writer's belief that the present areal distribution of redbeds in the Marshall formation has little bearing on the depositional history. The red colors are absent near the outcrops of the formation in southern and eastern Michigan and in the areas adjacent to the large anticlines in Shiawassee, Bay, and Arenac counties. This fact leads to the hypothesis that the red color has been destroyed by reduction and subsequent leaching where the beds are relatively near the surface, therefore, that the redbeds were originally much more widespread. If this thesis is correct, the present areal distribution of red color is due to processes in operation after the present structure of the Michigan basin was established.

5. *High feldspar content of sandstone in southwestern Michigan.*—The high feldspar content of the sandstones in southwestern Michigan is probably the best indication of a western source of sediments during Marshall time. It is very improbable that these feldspars came from the east as the feldspar content in the sandstone of eastern Michigan does not equal that of the sandstones on the southwest. The determination of a western source of sediments during Marshall time is not an entirely new concept, nor is it based solely on the petrographic studies described in this report. Stearns (1933) made a study of the minerals of the Marshall sandstone and concluded that the sandstones in western Michigan were closer to their source than those in eastern Michigan were to their source.

6. *Absence of thinning of sandstone on south and west, excepting in local areas, and thinning toward north-central part of state.*—The variations in thickness of

the sandstone strata do not offer much information regarding the depositional area. The beds of sandstone do not reflect the basin-like character of the area of deposition as do the Coldwater sediments. The thickest sandstones occur near the western, southern, and eastern margins of the present basin, but the sandstones in the west-central part of the basin are almost as thick. Irregularities in thickness of sandstones are to be expected, as less sand would accumulate in topographically high areas in a shallow sea than in adjacent lower areas. The area of thin Marshall in Oceana and Newaygo counties probably was relatively high on the floor of the Marshall sea. The area of thin Marshall in north-central Michigan is interpreted as an area of regional thinning toward the north, as the Marshall gradually decreases in thickness toward this area from the center of the state.

7. *Absence of any uniform and widespread basis for dividing Marshall formation.*—The impossibility of dividing the Marshall formation into two members is mentioned here to emphasize the opinion that the 130–300 feet of sandstone and siltstone accumulated under approximately the same conditions throughout the greater part of the state. Local influences, such as the topography of the sea floor, caused differences in sedimentation in some areas.

8. *Nature of Marshall-Michigan contact.*—The interfingering of the sandstones of late Marshall time with the shales and dolomites characteristic of the Michigan formation in the western half of the state is interpreted as indicating the absence of an unconformity between these two formations. Although an interfingering relationship of the Marshall and Michigan deposits is not evident in eastern Michigan, the two formations are considered to be conformable.

9. *Type of deposits in Michigan formation.*—The type of deposits in the Michigan formation are of particular importance in developing a history of Marshall time. The gypsum, anhydrite, limestone, and dolomite interbedded with gray shales and siltstones which overlie the Marshall formation are indicative of a change in climate and of a change in the conditions of deposition.

SEQUENCE OF EVENTS

The sea in which Coldwater sediments were deposited was of large extent. The area receiving the sediments was a large marine area with coarser clastics deposited in the near-shore area on the east and finer clastics and carbonates deposited farther seaward, away from the eastern source.

Marshall time was introduced by crustal movements both in the basin area and in the adjacent land areas, particularly on the west. The crustal movements resulted in the gentle uplift of granitic rocks in the Wisconsin Highland area, which then became an important source of sediments for the Michigan basin for the first time during the Mississippian epoch. The first sediments from this area to reach Michigan were fine-grained, red and buff sands which were deposited on the Coldwater shales. This change in the type of sediments being deposited in western Michigan marks the beginning of Marshall deposition.

In the eastern part of the state there was no sudden change in the type of deposits as the lower Marshall sediments were from the same source and of the same lithologic character as the near-shore facies of the Coldwater formation. The presence of conglomerate and coarse sandstone beds in the upper Coldwater-lower Marshall sediments probably signifies a gradual rise of the land surface on the east, resulting in a westward movement of the eastern shoreline of the sea. Throughout Marshall time the basin of deposition was becoming smaller and smaller due to the elevation of the surrounding land areas. This was accompanied by increasing aridity.

By the middle of Marshall time what had previously been a large depositional basin throughout Coldwater time, was a shallow-sea area with an irregular floor which was subject to wave and current action. The granitic rocks on the west continued to rise and most of the streams flowing eastward from this area were subject to frequent changes in volume and velocity as are the streams characteristic of arid and semi-arid regions. The coarsest material was deposited between the granitic area and the western margin of Michigan, but medium- and fine-grained sands were carried to that part of the Marshall sea covering the Southern Peninsula.

Near the middle of Marshall time the part of the Laurentian upland which had been the eastern source of Coldwater and lower Marshall sediments began to rise. This area was somewhat unstable throughout the Mississippian. The medium and coarse sands carried from the pre-Cambrian rocks of the Laurentian upland were deposited in eastern Michigan at the beginning of the Napoleon sandstone deposition. During the remaining Marshall time, medium-grained sands and some fine-grained sands were brought into the Marshall sea from the east and west. These sands were shifted about and deposited over the sea floor, with the thickest accumulations in the low areas and the thinnest on the topographically high areas.

Continued aridity, and evaporation of the shallow sea waters, resulted in further restriction of the Marshall sea. By this time it is probable that the sea was at least intermittently isolated from the ocean. The determination of the exact time that the first isolation of the Mississippian sea covering Michigan took place is difficult. It is possible that the separation accompanied the uplift of the area east of Michigan, which started the deposition of the Napoleon sandstone in the eastern part of the state.

Marshall deposition did not end simultaneously over the state. The first deposits of the Michigan formation accumulated in the quieter areas of the sea at the same time that Marshall sands were still being deposited in less quiet waters. It is possible that by this time an environment of great aridity existed over both the depositional area and the adjacent land areas. Streams which had been bringing sands into the state from the east no longer were able to carry anything but the finest clastics.

The Wisconsin Highland on the west continued to be drained by streams of

the torrential type, which were diminishing in number. They carried sand into the depositional area intermittently during the initial stages of deposition of the Michigan formation. The sand was spread out and deposited in an interfingering arrangement with the shale, dolomite, and gypsum deposits typical of the Michigan formation. Finally, the volume of the streams from the west was so reduced that they were unable to carry sand into the state. Mud and precipitates became the primary deposits throughout the Southern Peninsula, and Marshall time had come to an end.

The Marshall formation is thus seen to include the sediments which accumulated during the evolution from a large epicontinental sea surrounded by low land areas to a much smaller, shallow sea in which desiccation took place. Lane (1895, p. 19) summed up the significance of the Marshall formation by stating that "it marks the time at which the geological history of Michigan switches off from that of adjacent states and pursues its individual and peculiar course."

OIL AND GAS

Although the Michigan "Stray" sandstone is the largest natural-gas reservoir in Michigan, no commercial production of oil or gas has been attributed definitely to the Marshall formation. Hard (1938, p. 173) suggested that since the gas-producing sandstones are lateral fingers of Marshall sandstone in many areas, it is erroneous to conclude that gas is confined to sandstones of Michigan age.

It is apparent from an examination of driller's logs that in some areas drillers have erroneously referred to all sandstones at the base of the Michigan formation as Michigan "Stray" if they produce gas and as Marshall sandstone if they contain only water. In areas such as the Six Lakes field in Montcalm County where the gas producing sandstone directly overlies water-bearing sandstone (Hard, 1938, p. 159), there seems to be no question that the producing zone is Marshall in age.

Rawlins and Schellhardt (1936) and Bergquist (1938) have reviewed the discovery and production of gas from the Michigan "Stray" sandstone.

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